Visual attentional processes in adults with dyslexia

Judith Ann Buchholz

September 28, 2008

A thesis submitted for the degree of Doctor of Philosophy of The Australian National University.
Declaration

I, Judith Ann Buchholz, hereby declare that, except where acknowledged, this work is my own and has not been submitted for a higher degree at any other university or institution.

Judith Ann Buchholz
Acknowledgements

I would like to thank my family, Ralph and Rebecca, for their continued support throughout my research. Thank you especially to Ralph, who provided the IT support needed for processing the large amount of data collected. Also for his criticisms of and help in producing some of the figures.

I would also like to thank my friends, and my adult dyslexia cases for allowing me to subject them to psychophysical experiments over many years, both for my PhD research and also for my Master of Clinical Psychology research.

Thank you to Dr Anne Aimola Davies who provided help and guidance throughout my PhD. While we did not have a great deal of face-to-face discussion the internet proved invaluable, with many hundreds of emails being exchanged. I particularly thank Anne for her gentle approach to keeping me on track, while still allowing me leeway to approach the research how I felt.

I would also like to thank the members of my supervisory panel, Dr Elinor McKone, Dr Cobie Brinkman and Dr Mark Edwards, who provided invaluable advice and encouragement.
Thanks must also go to:

- Dr Timothy Bates, for providing the materials for the reading and spelling tests used for screening participants,
- Dr Jin Fan for providing the stimuli for use in the Attentional Network Test, Experiment 2, and
- Dr Michael Cook, who provided the eye monitoring equipment for my final experiment.

Finally, my research could not have progressed without the assistance of the technical and administrative staff in the ANU School of Psychology. In particular:

- Mary Dalton, who ensured the eye monitoring equipment was operational and maintained the computer systems necessary for running my research,
- Shane Pozzi and Petrina Daniel, who on several occasions had to set up a new office for me, and
- Kate Hogan, Jenny Sutton and Caroline Twang who ensured that I was informed of important course requirements, and provided with necessary documents both while in the USA and in Australia.
Publications and presentations arising from this research

The findings from the experiments discussed in Chapters 5, 6, 8, 9, and 10 that have been published and/or presented are presented below.

Papers


**Abstracts**


**Presentations**


Abstract

Deficits in sensory processing of visual and auditory stimuli, specifically that associated with the magnocellular/dorsal pathways, have been extensively reported in individuals with dyslexia (McArthur and Bishop, 2001; Stein, 2001). Furthermore, significant relationships have been reported between reading ability and performance on sensory processing tasks, both in the auditory and the visual modalities (Cestnick and Coltheart, 1999; Cestnick and Jerger, 2000; Talcott et al., 2002). However, a central role for phonological difficulties in reading difficulties independent of visual and auditory processing deficits has been demonstrated (Ramus et al., 2003b). The inconsistent results may be explained by individual differences in attentional processes (Marshall et al., 2001; Olson and Datta, 2002). While many studies have been carried out investigating attentional difficulties experienced by children with dyslexia, relatively few have examined these difficulties in adults with dyslexia (ADys). Furthermore, the relationship of these difficulties to the phonological deficits most often seen has yet to be fully explored. By determining the difficulties experienced by individuals with dyslexia, it may be possible to develop strategies to overcome them. This thesis primarily examines and compares processes of visual attention in adults with and without dyslexia. Each adult with dyslexia demonstrated phonological deficits consistent with this difficulty being a core deficit in dyslexia. A case-based approach, in addition to the usual group comparisons, has been adopted.

Chapter 1 provides background information to the nature of dyslexia, in-
cluding the difficulty of definition. Several theories of causality are also presented. In Chapter 2, the rationale behind the aims of this thesis is presented. Chapter 3 provides an explanation of, and the results from, the screening measures and analytical tools used in this thesis. These measures provide a comprehensive account of the cognitive and literacy abilities of the participants in the experiments that follow.

Chapters 4-10 present the findings of several experiments which have examined various aspects of attentional processing. In Chapter 4, visual selective attention is measured using a visual search paradigm. Both response time and accuracy of target detection as a function of set size were examined. A difficulty was demonstrated by the dyslexia cases only where searching involved a conjunction of stimulus features. However, while suggesting a compromised attentional system the nature of the visual search difficulties were not addressed in this experiment. For example, attention involves a number of processes, each of which may be responsible for the observed deficits in performance. Furthermore, the deficits may also be due to a slower attentional system, and/or relate to the processing of spatial and/or object information, and/or vary with visual field of presentation.

In Chapter 5, attentional dwell time is examined. The attentional blink (AB) refers to a deficit in the ability to identify a second target following a first target when both appear randomly within a rapid sequence of distractor items. Two tasks were completed which differed in the conceptual category of the target items (a red digit or letter) relative to the distractor items (all black digits). In the digit condition, all ADys cases showed a longer AB. In the letter condition, all participants showed improvement in accuracy compared to the digit condition, but three ADys cases continued to have longer AB compared to the control group. The results suggest that a) AB performance depends on task requirements, and b) the attentional system is compromised in dyslexia. However, examination of individual case performance suggests that prolonged attentional dwell time is not a core deficit in dyslexia.
Chapter 6 examines the space- and object-based components of attention using a spatial cueing paradigm. The group with dyslexia were generally slower to detect validly-cued targets. Costs of shifting attention toward the periphery when the target was invalidly cued were significantly higher for the group with dyslexia, while costs associated with shifts toward the fovea tended to be lower. Higher costs were also shown by the group with dyslexia for up/down shifts of attention in the periphery. A visual field processing difference was found, in that the group with dyslexia showed higher costs associated with shifting attention between objects in the left visual field. These findings indicate that adults with dyslexia have difficulty in both the space-based and the object-based components of covert visual attention, and more specifically to stimuli located in the periphery. However, Vecera (1994) found that object-based attention effects are sensitive to spatial manipulations. Thus, any difference observed between the control and dyslexia groups may merely reflect differences in space-based attentional orienting, rather than object-based attentional orienting.

An attempt to examine object-based attention in isolation was made in Chapter 7, using a methodology developed by Duncan (1984), which examines the accuracy of attending to two objects as opposed to one. The results of this experiment indicated a difficulty in processing rapidly presented stimuli in dyslexia. With respect to object-based processing, it appears that task difficulty may have been a confound. The results of the control group did not replicate those found by Valsangkar-Smyth et al. (2004), and performance was as poor as the dyslexia group.

In Chapter 8, a case study approach was taken to examine the role of visual attention and auditory memory processes in dyslexia. Individual data revealed that, although one adult with dyslexia showed overt visual attention deficits on a visual search task, and five showed auditory working memory deficits, the difficulty that all of the adults with dyslexia had in common was with covert shifts of attention toward and away from fixation. These results indicate that
deficits in overt visual attentional processing and working memory can be present with dyslexia, but neither is a necessary requirement. Overall, the results suggest that covert visual attention makes a significant contribution to phonological ability, which thus has implications for reading ability.

Chapter 9 examines the specificity of the attentional deficit observed in the previous chapters. Alerting, orienting and executive control of attention is investigated in five adult cases of dyslexia. Two spatial cueing tasks were employed. For the task requiring target detection, orienting difficulties were evident only in peripheral locations. While orienting attention to parafoveal stimuli was intact for this detection task, it was found to be impaired for the discrimination task. These results are discussed with respect to the methodological differences of the two tasks.

In addition to the unusual findings of Chapter 9, a specific attentional deficit has not been consistently demonstrated across studies of adults and children with dyslexia, possibly due to differences in methodology. In Chapter 10, three spatial cueing tasks were used to examine the effects of manipulating task variables, such as cue size, stimulus onset asynchrony (SOA), eccentricity and visual field of presentation, on attentional orienting. Visual orienting difficulties were observed when adjusting and maintaining attentional focus, but only under specific task conditions. Although increasing the size of the cue improved orienting performance, increasing stimulus onset asynchrony had a negative effect on this initial improvement. The poorest performance was observed at peripheral locations and in the right visual field. The observed difficulties may compromise reading since a difficulty in automatic orienting may affect the planning of eye movements, while a difficulty maintaining attention may hinder decoding due to increased distraction from nearby text. This study further highlights the need to consider task variables when designing attentional studies.

Finally, Chapter 11 provides a general discussion of the findings and their implications to dyslexia research.
Contents

Declaration ii
Acknowledgements iii
Publications vi
Abstract viii
List of Figures xviii
List of Tables xix

1 The nature of dyslexia 1
  1.1 Defining dyslexia .......................... 2
  1.2 Models of reading and dyslexia subtypes .... 5
  1.3 Theories of dyslexia .......................... 10
     1.3.1 Phonological deficit .................. 11
     1.3.2 Double-deficit .......................... 13
     1.3.3 Temporal processing deficit ............ 14
     1.3.4 Magnocellular deficit ................. 16
     1.3.5 Visual attention deficit ............... 19

2 Rationale 27
  2.1 Specificity of attentional deficit .......... 28
  2.2 A case for case studies .................... 30
2.3 Aims ............................................. 30

3 Screening and Assessment ............................................. 31
  3.1 The modified t-test ............................................. 32
  3.2 Psychometric Testing ............................................. 33
    3.2.1 The Wide Range Achievement Test-3rd edition .......... 33
    3.2.2 Dyslexia Adult Screening Test ............................. 35
    3.2.3 The Wechsler Adult Intelligence Scale-III ............... 38
    3.2.4 Test of Everyday Attention ................................. 42
    3.2.5 Brown Attention-Deficit Disorder Scales ................. 45
  3.3 Reading and Spelling ............................................. 47
    3.3.1 Test of non-word reading .................................. 47
    3.3.2 Test of reading and spelling ............................... 48
  3.4 Visual Acuity ................................................. 50
    3.4.1 Landolt ring-gap detection ................................. 50

4 Visual selective attention ............................................. 53
  4.1 Experiment 1 ................................................. 56
    4.1.1 Method ................................................... 57
    4.1.2 Results .................................................. 59
    4.1.3 Discussion ............................................... 61

5 Attentional blink ................................................. 65
  5.1 Experiment 2 ................................................. 69
    5.1.1 Method ................................................... 69
    5.1.2 Results .................................................. 72
    5.1.3 Discussion ............................................... 78

6 Space- and object-based attention ................................ 85
  6.1 Experiment 3 ................................................. 87
    6.1.1 Method ................................................... 88
    6.1.2 Results .................................................. 90
CONTENTS

6.1.3 Discussion .................................................... 93

7 Examining object based attention ................................... 95
  7.1 Experiment 4 ...................................................... 96
    7.1.1 Method .................................................... 96
    7.1.2 Results ................................................... 98
    7.1.3 Discussion ................................................. 100

8 Attention, memory and phonology .................................. 103
  8.1 Experiment 5 ...................................................... 105
    8.1.1 Method .................................................... 106
    8.1.2 Results ................................................... 107
    8.1.3 Discussion ................................................. 116

9 Specificity of attentional deficit .................................. 119
  9.1 Experiment 6 ...................................................... 122
    9.1.1 Method .................................................... 122
    9.1.2 Results ................................................... 123
  9.2 Experiment 7 ...................................................... 132
    9.2.1 Method .................................................... 132
    9.2.2 Results ................................................... 134
    9.2.3 Discussion ................................................. 140

10 Characterising the attentional orienting deficits observed in
    adults with dyslexia .............................................. 149
  10.1 Experiment 8 ...................................................... 154
    10.1.1 Method .................................................... 154
    10.1.2 Results ................................................... 157
    10.1.3 Discussion ................................................. 159
  10.2 Experiment 9 ...................................................... 161
    10.2.1 Method .................................................... 161
    10.2.2 Results ................................................... 162
10.2.3 Discussion ................................................. 168
10.3 Experiment 10 ............................................... 170
  10.3.1 Method ................................................ 170
  10.3.2 Results ............................................... 171
  10.3.3 Discussion ............................................. 179
10.4 Conclusions ................................................. 182

11 General discussion ........................................ 187
  11.1 Profile of adults with dyslexia .......................... 187
  11.2 Implications of findings for reading .................... 190
  11.3 Future directions ........................................ 192
    11.3.1 Attention and magnocellular function  ............ 192
    11.3.2 Other parietal cortex functions .................... 194
    11.3.3 Other brain areas .................................. 198
  11.4 Conclusions ............................................. 201

References .................................................. 206
# List of Figures

1.1 The dual-route cascaded model of reading aloud. ............ 7  
3.1 DAST profile for each dyslexia case. ....................... 37  
3.2 WAIS-III framework. ....................................... 39  
3.3 TEA framework. ............................................ 43  
3.4 Landolt-C test of visual acuity. ........................... 51  
4.1 Visual search procedure. ................................. 58  
4.2 Performance measures for serial search. .................. 60  
5.1 RSVP paradigm procedure ................................. 71  
5.2 Mean T1 response accuracy for each group. .............. 74  
5.3 Mean T1 response accuracy for the control group and each individual ADys case. .......................... 75  
5.4 Mean T2 response accuracy for each group. .............. 76  
5.5 Mean T2 response accuracy for the control group and each individual ADys case. .......................... 77  
6.1 The Egly paradigm. .......................................... 89  
6.2 Mean RT costs as a function of rectangle orientation, invalid-cue condition and visual field. .................. 92  
7.1 Object representation procedure. ........................ 97  
7.2 Response accuracy for each group in the object based attention task. ........................................... 98
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.3</td>
<td>Response accuracy for the control group and each ADys case in the object based attention task.</td>
</tr>
<tr>
<td>8.1</td>
<td>Results for within-object shifts of attention.</td>
</tr>
<tr>
<td>8.2</td>
<td>Distribution of performances on the psychometric and experimental measures.</td>
</tr>
<tr>
<td>9.1</td>
<td>No-cue condition: Effects of eccentricity.</td>
</tr>
<tr>
<td>9.2</td>
<td>Invalid-within condition: effects of eccentricity.</td>
</tr>
<tr>
<td>9.3</td>
<td>Invalid-across condition: effects of eccentricity.</td>
</tr>
<tr>
<td>9.4</td>
<td>Attentional Network Test procedure.</td>
</tr>
<tr>
<td>9.5</td>
<td>Alerting, orienting and conflict measures of attention.</td>
</tr>
<tr>
<td>10.1</td>
<td>Eye Monitoring Equipment.</td>
</tr>
<tr>
<td>10.2</td>
<td>An example of the valid-cue procedure.</td>
</tr>
<tr>
<td>10.3</td>
<td>RT as a function of eccentricity for each cue condition.</td>
</tr>
<tr>
<td>10.4</td>
<td>RT as a function of eccentricity (1°, 3°) and visual field for each stimulus onset asynchrony.</td>
</tr>
<tr>
<td>10.5</td>
<td>RT as a function of eccentricity for each cue size.</td>
</tr>
<tr>
<td>10.6</td>
<td>RT as a function of eccentricity (3°, 7°) and visual field for each stimulus onset asynchrony.</td>
</tr>
<tr>
<td>10.7</td>
<td>An example of the invalid-cue procedure.</td>
</tr>
<tr>
<td>10.8</td>
<td>RT as a function of cue size and eccentricity for each stimulus onset asynchrony.</td>
</tr>
<tr>
<td>10.9</td>
<td>RT costs as a function of stimulus onset asynchrony for each cue size.</td>
</tr>
<tr>
<td>10.10</td>
<td>RT costs as a function of eccentricity for each cue size.</td>
</tr>
<tr>
<td>10.11</td>
<td>RT costs as a function of eccentricity and stimulus onset asynchrony for each cue size.</td>
</tr>
<tr>
<td>10.12</td>
<td>RT costs as a function of visual field for each cue size.</td>
</tr>
<tr>
<td>10.13</td>
<td>Diagram of proposed attentional drift.</td>
</tr>
</tbody>
</table>
## List of Tables

3.1 Control group performance on the WRAT-3. .................. 34
3.2 Dyslexia group and individual ADys case performance on the WRAT-3. ................................................ 34
3.3 Subtests of the Dyslexic Adult Screening Test. ................. 36
3.4 Unique abilities tested by the WAIS-III. ........................ 40
3.5 Control group age and cognitive function. ....................... 41
3.6 Dyslexia group and individual case age and cognitive function. . 41
3.7 Control group (n=16) and dyslexia case scaled scores on TEA. . 44
3.8 Control group and dyslexia case T-scores on BADDS. .......... 47
3.9 Control and dyslexia group, and dyslexia case scores on non-word reading. ............................................ 48
3.10 Control and dyslexia group, and dyslexia case scores on reading and spelling tests. ..................... 50

5.1 Accuracy of single target identification as a function of notional lag. ............................................. 72

8.1 Scores for psychometric and experimental measures. ....... 108
8.2 Correlations between variables. ................................ 115

9.1 Summary RTs of no-cue, invalid-cue and valid-cue conditions. . 124
9.2 Summary RT costs associated with attention shifts. ........... 129
9.3 Accuracy and RTs as a function of flanker condition. ........... 136

11.1 Attentional profile of dyslexia individuals. ..................... 189
Chapter 1

The nature of dyslexia

The word *dyslexia* was first used by a German ophthalmologist when referring to reading difficulties caused by cerebral damage or injury (e.g., Berlin, 1887). Today, this is referred to as *acquired dyslexia*. In contrast, Morgan (1896) provided possibly the first account of reading disabilities without brain damage, that is, *developmental dyslexia*¹. The relationship between acquired and developmental forms of dyslexia has received much discussion. One school of thought holds that insights gained from acquired dyslexia may provide a better understanding of developmental dyslexia (Castles and Coltheart, 1993; Drew, 1956; Marshall, 1985). In contrast, others believe a comparison between the clinical syndromes of the developing child and an adult with brain injury are illogical (Ingram, 1963), or beyond the limitations of analogy (Critchley, 1970), or contain theoretical and methodological difficulties (Snowling, Bryant, and Hulme, 1996a). Nevertheless, research into both forms of dyslexia has provided a) a better understanding of reading (and writing) processes, b) a means of further defining the sub-categories of dyslexia, and c) the basis of many theories of dyslexia.

¹For reviews of the early history of research in dyslexia, see Critchley (1970), Drew (1956), and Richardson (1992).
Chapter 1: The nature of dyslexia

In his book, *Reading, Writing and Speech Problems in Children*, Samuel T. Orton (1937) promoted the concept of *strephosymbolia*. Orton had observed that the children with reading problems tended to read words backwards, or to write in mirror images. He interpreted these phenomena as reflecting incomplete cerebral dominance. Specifically, he argued that visual information is represented in a mirror fashion in the left and right hemispheres, and that a lack of sufficient development of the dominant hemisphere for language (left) resulted in confusion in reading and writing. Although Orton’s terminology is no longer used, and some of the details of his theory are incorrect, the characterisation of a problem in brain activity important for the cognitive functions underlying reading, and the difficulties observed in developmental dyslexia, is still under investigation today.

The prevalence of developmental dyslexia has been estimated at 5 - 10% of the school population (Shaywitz, 1998; Snowling, 2000). Despite the vast amount of research in developmental dyslexia, its aetiology remains speculative and a globally acceptable simple definition has yet to be determined. Similarly, many theories have been put forward to account for developmental dyslexia, each focusing on different cognitive and/or brain functions.

In this chapter, I discuss the difficulties associated with defining developmental dyslexia. These are followed by an examination of some models of reading, which in turn provide a basis to further delineate developmental dyslexia into subtypes. Finally, literature pertaining to several theories of dyslexia will be discussed.

1.1 Defining dyslexia

The issue of classification is fundamental to scientific progress in any field, no less so in the field of reading disability. As with other complex behaviours, the prevalence estimates of dyslexia depend in part on its definition, severity and
Without a working definition of dyslexia, early research suffered from the use of a “multiplicity of terms” to refer to reading difficulties (Naidoo, 1972). Rutter and Yule (1975), commented on the “chaotic and confusing” terminology used to describe reading difficulties, further stating that a vagueness in definitions, a looseness in the use of words, and disputes about the nature of dyslexia, specifically about its existence, were contributors of the chaos. This dispute of the existence of dyslexia was still an issue as recently as 1994 (see Stanovich, 1994).

There are many definitions of dyslexia but no consensus (for review see Rice, 2004, Appendix 1). In an effort to provide a working definition of dyslexia, the World Federation of Neurology (WFN 1968) described dyslexia as a “specific reading disability which occurs despite conventional instruction, adequate intelligence and socio-cultural opportunity”. While this definition is widely used by researchers today, it is not without criticism. It has been argued that the terms used in this definition are difficult to operationalize, for example, *what is adequate IQ?* or *adequate opportunity?* (see Catts, 1989; Kamhi, 1992). Also, because this definition is based on exclusionary criteria, it suggests that dyslexia cannot be diagnosed in a child with a poor socio-economical background.

An alternative definition was proposed by the British Psychological Society as follows, “Dyslexia is evident when accurate and fluent word reading and/or spelling develops very incompletely or with great difficulty” (Reason, Frederickson, Heffernan, Martin, and Woods, 1999). While this definition provides for all children with literacy difficulties, it is no more precise than that given by the WFN. For the purposes of research it suffers from being over-inclusive.

In the UK, children were described as having a specific learning disability (SpLD) or specific reading difficulties if there was a discrepancy between their expected attainment in reading, as predicted by their age and IQ, and their socio-cultural attitudes.
actual reading ability (e.g., Ingram and Mason, 1965; Rutter and Yule, 1975). The discrepancy criterion often used in research is that a child should have an IQ of 90 or above, and a reading age at least two years behind the child’s chronological age group. The basic assumption here is that children with average IQ should develop normal reading skills. Children with low IQ and poor reading skills constitute general or “garden variety” poor readers\(^2\). However, there are several problems inherent in the use of IQ in this definition. First, IQ and reading are not strongly related. Children with low IQ have been shown to read perfectly well, albeit they may have some comprehension difficulties (Fildes, 1921; Siegel, 1988; Vellutino, Scanlon, and Lyon, 2000). Recent studies have also indicated that IQ and reading are unrelated at the molecular genetic level (Luciano, Lind, Duffy, Castles, Wright, Montgomery, Martin, and Bates, 2007). Second, limited access to knowledge in books, presumably from reading less, may lead to a decline in Verbal IQ as the poor reader ages (Siegel, 1999; Stanovich, 1986). Also, performance on IQ tests is sensitive to other factors such as working memory (Borella, Carretti, and Mammarella, 2006; Colom, Flores-Mendoza, and Rebollo, 2003; Haavisto and Lehto, 2005; Kyllonen and Christal, 1990). Another important objection is that the IQ measure combines both innate and acquired ability, not purely innate ability (Ceci, 1991; Mackintosh, 1998). As with the previous exclusionary definition of dyslexia, this definition may be justified on the basis that it allows identification of potential research participants (Nicolson, 1996; Torgeson, 1989). However, a major limitation of the discrepancy definitions is the lack of positive diagnostic criteria.

A further difficulty in defining dyslexia arises due to the diverse characteristics shown in this disorder, including behavioural features such as clumsiness and slowness in processing stimuli. Some researchers have suggested that a wider view needs to be taken in defining the nature of dyslexia, one which is

\(^2\)This is not identical to “backward reader” as used by Rutter and his colleagues (Rutter and Yule, 1975; Yule, Rutter, Berger, and Thompson, 1974), as these readers were identified on a reading score in relation to the child’s age and not IQ.
not limited to reading (Miles, 1986; Nicolson and Fawcett, 1990). Indeed, it has been suggested that the reading deficits observed in dyslexia are “merely a symptom of a more general and pervasive deficit in the acquisition of skill” (Nicolson and Fawcett, 1990, pg. 160). This view is reflected in the Bangor Dyslexia Test (Miles, 1982) and the Dyslexia Adult Screening Test (Fawcett and Nicolson, 1998), which assess performance on a variety of tasks which appear unrelated to reading, such as recalling a series of digits in reverse order.

As can be seen from the previous discussion, developing a working definition of dyslexia has proved difficult. As such, a conclusive definition has yet to be established.

1.2 Models of reading and dyslexia subtypes

Models of reading provide a means for evaluating the proximal causes for reading difficulties, that is, the abnormality of the reading system (a cognitive system) that directly causes the observed abnormal reading behaviours.

An early model of reading attempted to incorporate and expand on Orton’s idea of cerebral dominance in reading. This balance model (Bakker, 1979, 1992) postulated that early reading relied on strategies mediated by the right hemisphere (RH), that is, those relying on visual features of words. For advanced reading, strategies mediated by the left hemisphere (LH) are used, that is, those relying on phonological knowledge. Therefore, as reading skills advance, a shift in reading strategies from the right to the left hemisphere becomes necessary. Based on this theory, Bakker (1979; 1992) classified children with dyslexia into two types: P-type where reading strategies remain focused on perceptual features of the text, that is, the reading strategies fail to shift from RH to LH, and L-type where the shift occurs prematurely and children rely on the linguistic strategies in early reading development. Hynd (1992) pointed out that this model of reading is inadequate as a) right hemisphere
involvement in early reading has not been shown in good readers, and b) the model does not explain how the shift occurs.

Many researchers have suggested that reading develops through a progression of phases or stages (e.g., Chall, 1996; Ehri, 1995; Frith, 1985; Morris, Bloodgood, and Lomax, 2003). These models propose the development of different cognitive processes at distinct points; an initial stage, a middle stage and a final stage. Generally, the first stage is dominated by attention to global visual features of word and letter shape (picture recognition), such as the rounded sections in the letters b, p and o. In the second stage, phonic decoding based on single letter-to-sound associations is predominant. Characteristic of the final stage is multi-letter decoding where whole strings of letters may be accessed and associated with their corresponding phoneme clusters (orthographic word recognition). With reading practice in this final stage, recurring letter patterns become consolidated in memory to form a sight vocabulary (Ehri, 1995). As reading skill develops, low-level processes such as word recognition become efficient, freeing attentional resources for high-level processes such as comprehension (Herdman and LeFevre, 1992). A failure to complete any of these stages may result in a reading difficulty. These models have received some criticism due to the assumption that all children are alike and receive the same level of literacy instruction. However, reading is a learned skill and individual differences occur that question the notion of stages in reading development.

The dual route model (DRM) of reading aloud (Jackson and Coltheart, 2001) has provided an alternative to the stage models of reading development. According to this model, reading acquisition involves establishing two partially independent reading pathways (or cognitive sub-systems), determined by the characteristics of the words which are processed (see Figure 1.1). Retrieving the appropriate phonological form of a particular orthographic stimulus from a mental dictionary is referred to as the lexical route of reading, and the application of grapheme-to-phoneme correspondence (GPC) rules is referred to as the nonlexical route.
Developing readers must acquire both these routes to become skilled readers. These routes may develop at different, or given certain prerequisites, concurrent rates. Typically, the integrity of the lexical route is examined by measuring the ability to read irregular words (those that deviate from GPC rules) such as 
\textit{yacht}. Reading of novel non-words \textsuperscript{3}, such as \textit{bimp}, provides an indication of the ability to construct a phonological form for a letter-string using GPC rules. Theoretically, regular words may be read via either route. Accordingly, a \textit{phonological} subtype of dyslexia is characterised by poor non-word reading but preserved ability to read irregular words. This subtype relies on a global reading procedure based on the activation of specific word knowledge (the lexical route, sight vocabulary) and does not make effective use of the GPC rules (the nonlexical route). As a result, this subtype cannot deal with new or unusual words. Poor phoneme awareness has been systematically

\textsuperscript{3}This refers to orthographically correct letter strings that do not spell a word. They may also be referred to as pseudo-words.
reported in this subtype of dyslexia (Broom and Doctor, 1995a; Howard and Best, 1996; Snowling and Hulme, 1989). A phonological impairment of this type could impair development of the nonlexical route by impairing acquisition of GPC rules, that is, it could act as a distal cause of phonological dyslexia. If a child is unable to parse the phonological signal into separate phonemes, then a difficulty in learning the associations between individual letters (or graphemes) and individual phonemes would be expected.

In contrast, the *surface* subtype of dyslexia show impairment in irregular word reading but not non-word reading. They rely on an analytic approach to reading based on general word knowledge about spelling-sound correspondences (the nonlexical route) and do not make effective use of phonological information about specific words stored in a mental dictionary (the lexical route) (Broom and Doctor, 1995b; Castles and Coltheart, 1996; Goulandris and Snowling, 1991; Romani, Ward, and Olson, 1999; Samuelsson, 2000). Consequently these individuals read laboriously, as they cannot see letters and words as visual wholes. There is also a population of readers who show difficulties with both the lexical and nonlexical procedures, known as the *mixed* subgroup of dyslexia. These readers are usually the most severely handicapped educationally. The dual-route model of reading has been extended upon to include other characteristics of the reading process, and thus allow further predictions about the types of reading errors that may occur in the population.

The connectionist multi-trace model of polysyllabic reading (Ans, Carbonnel, and Valdois, 1998) incorporates an attentional component into the reading process. According to this model, there are two types of reading process, global and analytical, which differ in the size of the visual attention window (VAW) through which information from the orthographic input is extracted. When reading, global processing occurs first, with a large VAW which extends over the letter sequence and activates word traces in memory (this is similar to the lexical route of the DRM). If this fails then the VAW narrows to allow the analytic process to proceed. Analytic processing occurs from
left-to-right, with phonological output being generated and held in short-term memory for each group of letters within the VAW, until all letters have been processed (this is similar to the nonlexical route of the DRM). The analytic procedure necessarily creates memory traces of relationships between orthographic and phonological nonlexical segments. Based on this model, Valdois and colleagues (Valdois, Bosse, and Tainturier, 2004) propose that new lexical knowledge can be acquired in two ways by beginning readers, either by being provided with the complete phonological-orthographic correspondence or by generating the entire phonological sequence through analytic procedures (self learning, see Share, 2004). These researchers also suggest that the analytic procedure would become ineffective in the presence of a phonological deficit and that this would affect the development of nonlexical knowledge and/or the maintenance of phonological information in short-term memory. This would lead to either a difficulty in reading pseudo-words (phonological dyslexia) or both pseudo- and irregular words (mixed-type dyslexia). In contrast, a visual attention disorder in which the VAW is reduced would interfere with the global reading procedure and therefore the establishment of lexical knowledge. In this case, irregular word reading would be difficult (surface dyslexia). This proposal presents a specific phonological deficit as a factor in the aetiology of phonological dyslexia, and a specific visual attentional deficit as a factor in the aetiology of surface dyslexia.

Evidence for subtypes of dyslexia, based on the pattern of reading deficit, has led researchers to theorise that the differences in the patterns shown by these subtypes reflect different aetiologies (Castles and Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang, and Petersen, 1996; Stanovich, Siegel, and Gottardo, 1997). Specifically, surface dyslexia is characterised by a developmental delay, whereby the reading system (and therefore the reading ability) of the individual reaches maturity at a later stage in their development. As

---

4The reverse may also be true.

5Although the usefulness of subtype classification has been questioned since all taxonomies leave a substantial number of children unclassified (see Griffiths, 1999).
Chapter 1: The nature of dyslexia

a consequence, reading difficulties do not persist into adulthood for these individuals. In contrast, phonological dyslexia is characterised by a cognitive deficit, that is, there is a permanency in the underlying impairment/s causing the reading difficulty (see also Griffiths and Snowling, 2002; Gustafson, 2001; Sprenger-Charolles, Lacert, Bechennec, Cole, and Serniclaes, 2000).

It should be noted, however, that the characteristics commonly used as a basis for classifying subtypes may reflect differences in teaching method and strategic choice, rather than differences in learning aptitude (Hendriks and Kolk, 1997; Zabell and Everatt, 2002). Furthermore, readers have been observed, over a two year period, to move from one of these subtypes to the other (Snowling and Nation, 1997).

It is often difficult to categorise adults with dyslexia. Specifically, these adults may demonstrate both phonological and surface characteristics suggesting a mixed subtype. However, the surface characteristics may be due to less exposure to reading, rather than a difficulty with global reading, per se.

For the purposes of this research, adults with reading difficulties have been selected on the basis that they demonstrate phonological difficulties, with or without concomitant difficulties in reading irregular words.

1.3 Theories of dyslexia

Researchers have examined environmental, biological and cognitive factors in an attempt to determine the basis of the proximal cause, that is, the distal or antecedent cause/s of the reading system abnormalities (Jackson and Coltheart, 2001). These investigations have resulted in the formulation of many hypotheses, of which several are examined in this section.
1.3.1 Phonological deficit

Walton and Walton (2002) have defined phonological awareness as “conscious access to the component sounds of speech within words and the ability to manipulate these sounds . . . primarily the sound units of onset and rime . . . and phonemes” (pg. 79-80). This construct is dynamic in that the phonological abilities develop over time (Anthony, Lonigan, Burgess, Driscoll, Phillips, and Cantor, 2002; Norris and Hoffman, 2002). Furthermore, it has been suggested that phonological awareness may be associated with at least three component skills, namely general cognitive ability, verbal short-term memory and speech perception (McBride-Chang, Wagner, and Chang, 1997).

According to the phonological deficit hypothesis (Frith, 1997; Snowling, 2000; Stanovich and Siegel, 1994; Vellutino, Fletcher, Snowling, and Scanlon, 2004), developmental dyslexia is a direct result of an underlying phonological impairment. This impairment occurs in one, or more, of the functions related to processing phonemes and may be reflected in poor speech and/or other linguistic skills. This seems a reasonable hypothesis given that one of the most clearly established difficulties in dyslexia is in terms of phonological skill (Brady and Shankweiler, 1991; Bruck, 1992; Felton, Naylor, and Wood, 1990; Fox and Routh, 1980; Frith, 1995; Gathercole and Baddeley, 1990; Mody, Studdert-Kennedy, and Brady, 1997; Pennington, Van Orden, Smith, Green, and Haith, 1990; Snowling and Rack, 1991). For example, children with developmental dyslexia have shown impairment on phonological processing tasks such as phonemic awareness (knowledge of word structure), phonological learning and non-word repetition (Brady and Shankweiler, 1991; Fox and Routh, 1980; Pennington et al., 1990). In addition, poor performances in short-term memory, long-term memory, picture naming and verbal repetition have been reported in dyslexia. These deficits are consistent with a deficiency in the use of phonologically-based information (Rack, 1994). Support for a causal link

---

6 Onset refers to the opening consonant phoneme(s) of a syllable; rime refers to the rest of the syllable, that is, the obligatory vowel and closing consonant phoneme(s).
between phonological processing ability and learning to read has come from several research studies of normal reading. For example, a good predictor of reading ability is the knowledge a child has of the phonological structure of language (Bradley and Bryant, 1983). Reading progress has been shown to be related to phonological awareness (for a review see Goswami and Bryant, 1990), and phonological awareness training has been shown to improve learning to read (for a review see Castles and Coltheart, 2004). Finally, the persistence of phonological difficulties in compensated adults with dyslexia\(^7\) (Bruck, 1992; Fawcett and Nicolson, 1995a) suggests that this may be a core problem in developmental dyslexia.

While these findings provide strong support for the phonological deficit hypothesis there have been several reports of cases of developmental dyslexia showing good phonological skill (Hanley and Gard, 1995; Curtin, Manis, and Seidenberg, 2001; Valdois, Bosse, Ans, Carbonnel, Zorman, David, and Pellat, 2003). Also, the difficulties with phonological awareness, associated with dyslexia, is not consistent across languages. Rather, the difficulties appear specific to children learning to read irregular or “opaque” orthographies, that is, where the relationship between spellings and their sounds are inconsistent (e.g., English, *pint* vs *mint*). In more regular or “transparent” orthographies, where such relationships are consistent (e.g., German, Italian, Spanish), children rapidly develop an awareness of the phonic structure of spoken words (Cossu, 1999). In English, the correspondences between phonemes and graphemes (letters or letter-groups used to transcribe phonemes) are complex (Jackson and Coltheart, 2001). Explicit instruction in the isolation, identity, categorisation, blending, segmentation and deletion of phonemic units aids in their learning (Cardoso-Martins, 2001; Ehri, Nunes, Willows, Schuster, Yaghoub-Zadeh, and Shanahan, 2001). Thus, reading instruction plays a crucial role in the development of phonemic awareness. In addition, evidence suggests an interactive relationship between phonological skills and reading.

\(^{7}\text{i.e., they received a diagnosis of dyslexia as children, but now show improved reading.}\)
Theories of dyslexia

(Korkman, Barron-Linnankoski, and Lahtiu-Nuutila, 1999; Snowling, Goulandris, and Defty, 1996b), although this interaction is not inevitable (Caravolas, Hulme, and Snowling, 2001; Viise, 1996). While the phonological deficit hypothesis suggests a deficit mainly at the cognitive level, specifically in the language system, other hypotheses propose non-linguistic factors either as alternatives to a phonological deficit, or as more ultimate causes of such a deficit.

1.3.2 Double-deficit

The double-deficit hypothesis explicitly postulates that a phonological deficit (accuracy) and a deficit in rapid automated naming (RAN) of letters or symbols (fluency) represent two independent sources of reading disability (Wolf and Bowers, 1999; Wolf, Goldberg O'Rourke, Gidney, Lovett, Cirino, and Morris, 2002). For a recent review of evidence for the double-deficit hypothesis see Vukovic and Siegel (2006). Research has provided some evidence for naming speed deficits in developmental dyslexia (Denckla and Rudel, 1976; Wimmer, Mayringer, and Landerl, 2000; Wolf and Bowers, 1999), suggesting that the ability for rapid naming contributes to reading acquisition above that accounted for by phonological skills (Manis, Doi, and Bhadha, 2000; Manis, Seidenberg, and Doi, 1999; Wolf and Bowers, 1999). In particular, it has been reported that difficulties in rapid naming appear to be the basis for dyslexia in languages having a regular orthography (Landerl, 2001). Furthermore, evidence has been provided that the presence of deficits in both phonological skills and naming speed produce more severe reading difficulties than when only one of these deficits is present (Miller, Miller, Bloom, Jones, Lindstrom, Craggs, Garcia-Barrera, Semrud-Clikeman, Gilger, and Hynd, 2006; Wolf and Bowers, 1999; Wolf, Bowers, and Biddle, 2000). Rapid naming also appears to be more strongly related to reading speed and measures of orthographic knowledge than phonological skills (Bowers, Sunseth, and Golden, 1999; Manis, Seidenberg, and Doi, 1999). However, there are difficulties associated
with this hypothesis. For example, contrary to the two deficits being independent, children with dyslexia tend to exhibit both a phonological and a naming speed disorder (Wolf et al., 2002). Furthermore, Schatschneider et al. (2002) have shown that the reading impairment found in children with a double deficit could be a statistical artifact due to such a relationship (see also Compton, DeFries, and Olson, 2001). This is further stressed by the findings that phonological interventions reduce the occurrence of naming speed deficits (Levy, Bourassa, and Horn, 1999; Lovett, Steinbach, and Frijters, 2000). Thus, it may be incorrect to categorise naming speed separately from phonological skills. Indeed, there seems to be some uncertainty as to whether RAN represents a phonological subprocess, or acts as a stressor of the phonological system through retrieval demands of phonological codes (Cutting and Denckla, 2001). Rapid naming is predictive for poor readers but not average readers. There may be qualitative differences between the two groups, rather than the poor readers simply representing the ‘tail’ of a normal distribution of reading ability (Meyer, Wood, Hart, and Felton, 1998). Rapid naming tasks require a complex ensemble of attentional, perceptual, conceptual, memory, phonological, semantic and motoric subprocesses, with emphasis on precise timing within and across components (Wolf et al., 2000). Given this complexity, it is difficult to delineate the contribution each makes to the overall deficit observed in individuals with dyslexia.

### 1.3.3 Temporal processing deficit

Tallal (1984) has proposed that the phonemic deficit seen in dyslexia is a symptom of a more general deficit in processing rapid temporal sequences. Support for this proposal has come from studies examining sequential processing in both the visual and auditory modalities.

Temporal processing can be broadly defined to include any type of processing required when two or more stimuli are presented in sequence. Four
subdivisions for temporal processing have been proposed: detection (or identification) of a single stimulus, determination of stimulus individuation, temporal order judgment and sequence discrimination (Farmer and Klein, 1995). The ability to detect the presence of a single stimulus amongst two or more, based on some particular feature such as colour or pitch, is necessary for successful performance. Research suggests that individuals with dyslexia are as able as those without dyslexia in detecting and identifying a single stimulus (Blackwell, McIntyre, and Murray, 1983; Klein, Berry, Briand, D’Entremont, and Farah, 1990; Tallal, 1980). In contrast, evidence for impaired ability at stimulus individuation, temporal order judgment and sequence discrimination across modalities have been extensively reported in both adults and children with dyslexia (Ben-Artzi, Fostick, and Babkoff, 2005; Eden, VanMeter, Rumsey, and Zeffiro, 1996b; Galaburda, 1993; Kinsbourne, Rufo, Gamzu, Palmer, and Berliner, 1991; Laasonen, Tomma-Halme, Lahti-Nuuttila, Service, and Virsu, 2000; Martin and Lovegrove, 1987; Tallal, Stark, and Mellitis, 1985). Laasonen and colleagues (Laasonen, Service, and Virsu, 2001, 2002) found a general correlation between dyslexia and temporal input processing, and they also reported significant overlap in performances by their dyslexia and normal reading groups. They suggested that poor temporal processing did not sufficiently explain developmental reading difficulties.

It is possible that the temporal processing deficit observed in dyslexia is a result of an attentional difficulty, for example, either in directing attention to each successive stimulus or in maintaining attention for a required time on each stimulus, to allow for processing and identification. Indeed, it has been proposed that these difficulties are secondary to a more fundamental attention deficit, specifically a sluggish attentional system, and reflect a reduced ability to attend to stimuli in all modalities, which can be associated with parietal cortex function (Hari and Renvall, 2001).
1.3.4 Magnocellular deficit

The magnocellular hypothesis (Stein, 2001; Stein and Walsh, 1997) is a comprehensive attempt to explain the wide range of behaviours associated with developmental dyslexia. In addition to language difficulties, deficits in visual processing consistent with abnormalities in one of the two parallel retinocortical pathways in the visual system, specifically the magnocellular (M) pathway, have been reported in developmental dyslexia. This pathway is highly sensitive to visual information related to space (such as movement, depth and positional changes), which are important in determining where an object is located (Logothetis and Sheinberg, 1996; Merigan and Maunsell, 1993; Schiller, Logothetis, and Charles, 1990a,b). It also preferentially transfers visual information of high temporal frequency, low spatial frequency, low luminance and low contrast for processing (Merigan and Maunsell, 1993).

Children with dyslexia have shown impaired performance on tasks associated with all levels of this pathway (see Stein, 2001). For example, performance deficits consistent with abnormalities in M(y) ganglion cell activity at the retinal level have been reported in children (Pammer and Wheatley, 2001) and adults (Buchholz and McKone, 2004). Also, the contrast sensitivity function of children with dyslexia has been shown to be different to that of children who do not have dyslexia. Specifically, they are less sensitive at low spatial frequencies (1, 2, and 4 cycles deg$^{-1}$), while at higher spatial frequencies (8 and 12 cycles deg$^{-1}$) they are equally or more sensitive (Borsting, Ridder, Dudeck, Kelley, Matsul, and Motoyama, 1996; Cornelissen, Richardson, Mason, Fowler, and Stein, 1995; Livingstone, Rosen, Drislane, and Galaburda, 1991; Martin and Lovegrove, 1987; Talcott, Hansen, Willis-Owens, McKinnell, Richardson, and Stein, 1998). According to Habib (2000), this difference in contrast sensitivity function provides the best demonstration of a low-level visual deficit in dyslexia. Physiological (Kubova, Kuba, Peregrin, and Novakova, 1996; Livingstone, Rosen, Drislane, and Galaburda, 1991; Maddock, Richardson, and
Theories of dyslexia

Stein, 1993; May, Lovegrove, Martin, and Nelson, 1991), neuroimaging (Demb, Boynton, and Heeger, 1998; Eden, VanMeter, Rumsey, Maisong, Woods, and Zeffiro, 1996a) and psychophysical studies (Brannan and Williams, 1988; Cornelissen, Richardson, Mason, Fowler, and Stein, 1995; Everatt, Bradshaw, and Hibbard, 1999; Martin and Lovegrove, 1987; Slaghuis and Ryan, 1999; Talcott, Hansen, Assoku, and Stein, 2000; Talcott, Hansen, Willis-Owens, McKinnell, Richardson, and Stein, 1998) have shown individuals with dyslexia to be less sensitive than normal readers to moving or rapidly presented stimuli. Since reading requires fast and accurate processing of transient stimuli, a deficit in motion processing is likely to be accompanied by difficulty in reading. Indeed, associations have been reported between coherent motion and accuracy of phonological decoding in adults (Talcott et al., 1998) and children (Talcott, Witton, Hebb, Stoodley, Westwood, France, Hansen, and Stein, 2002), and between coherent motion and the ability to accurately localise and decode letters in children (Cornelissen and Hansen, 1998; Cornelissen, Hansen, Gilchrist, Cormack, Essex, and Frankish, 1998; Talcott, Witton, Hebb, Stoodley, Westwood, France, Hansen, and Stein, 2002). Results of a recent study have suggested the presence of two distinct motion processing deficits in developmental dyslexia, each associated with different reading deficits (Wilmer, Richardson, Chen, and Stein, 2004). Specifically, an association between coherent motion thresholds and accuracy on reading skills, and an association between velocity discrimination and reading speed.

Deficits associated with visual persistence have also been reported. Any continued visual response to a stimulus occurring after the removal of the stimulus, which is indistinguishable from that occurring in its presence, is called visual persistence. In order to read well, some degree of visual persistence would be expected to enable stimulus transmission for subsequent stages of processing. If this duration is too short or too long then reading performance would be impaired (Riding and Pugh, 1977). A measure of M-pathway sensitivity to visual persistence can be determined by measuring the time required
to distinguish two visual stimuli presented in rapid succession. Findings have shown visual persistence to be consistently longer, by as much as 100 msec, compared to normal readers (Badcock and Lovegrove, 1981; Slaghuis, Lovegrove, and Davidson, 1993; Stein, 1991).

Anatomical abnormalities in the magnocellular layers of the lateral geniculate nucleus (mLGN) have also been reported in individuals with dyslexia. For example, Livingstone and colleagues (Livingstone, Rosen, Drislane, and Galaburda, 1991) conducted post-mortem examinations of the brains of five individuals who had dyslexia. They reported that these layers contained fewer cells than those of matched normal readers, and these cells were more than 27% smaller and were more variable in size and shape. However, it should be noted, from small samples such as this, that the findings are suggestive rather than definitive.

The presence of visual deficits consistent with a magnocellular deficit in adults with dyslexia suggests that this may be a distal cause of dyslexia, preventing the normal development of the reading system. Although how this deficit operates is open for discussion. Findings of the few studies which have examined low-level visual processing abilities in dyslexia subtypes suggest that the visual perceptual deficits may be particular to those subtypes which show some phonological impairment (Borsting, Ridder, Dudeck, Kelley, Matsul, and Motoyama, 1996; Cestnick and Coltheart, 1999; Ridder, Borsting, Cooper, McNeel, and Huang, 1997; Spinelli, Angelelli, DeLuca, DiPace, Judica, and Zoccolotti, 1997; Talcott, Hansen, Willis-Owens, McKinnell, Richardson, and Stein, 1998). That is, the association between the M-pathway and reading is specific to the the nonlexical reading route (but see Sperling, Lu, Manis, and Seidenberg, 2003). However, a recent study by Williams and colleagues (Williams, Stuart, Castles, and McAnally, 2003) failed to demonstrate significant differences in contrast sensitivity for any dyslexia subtype when compared to a control group. They suggest that the deficits shown in previous research may be characteristic of severely affected individuals. Other studies
have also failed to find deficits in low-level M-pathway functions (Gross-Glenn, Skottun, Glenn, Kubshch, Lingua, Dunbar, Jallad, Lubs, Levin, Rabin, Park, and Duara, 1995; Hayduk, Bruck, and Cavanagh, 1996; Johannes, Kussmaul, Munte, and Mangun, 1996). It has been suggested that these inconsistent studies may arise from methodological differences (Martin, 1995), a lack of control of sample heterogeneity, or a difference in subtype representation (Borsting, Ridder, Dudeck, Kelley, Matsul, and Motoyama, 1996; Hogben, 1996).

The magnocellular impairments in dyslexia have been disputed as they are often slight and have not been found in all dyslexic individuals (Skottun, 2000; Stein, Talcott, and Walsh, 2000). The inconsistent findings of low-level visual deficits in individuals with dyslexia present a difficulty for the magnocellular theory. One alternative proposal regarding the visual deficits shown in dyslexia, is that these arise from dysfunction in higher visual areas that receive predominantly magnocellular input, while the more peripheral areas may function normally. This dysfunction may therefore be reflected in deficiencies in performance on low-level visual tasks, associated with the magnocellular pathway, which rely on top-down processes. This will be discussed in the next section describing the visual attention deficit hypothesis of dyslexia.

1.3.5 Visual attention deficit

Parietal cortex function

The posterior parietal cortex (PPC) is a major output area that receives mLGN afferents via areas V3 and V5 in extrastriate cortex. The PPC shows properties which are M-like, such as sensitivity to direction of motion, and relative insensitivity to colour and form (Motter and Mountcastle, 1981). It may play a role in reading since it has been shown to be important for spatial relations and visually guided movements (e.g., Pisella, Grea, Tilikete, Vighetto, Desmurget, Rode, Boisson, and Rossetti, 2000), visuo-spatial attention (e.g., Bisley and
Chapter 1: The nature of dyslexia

Goldberg, 2003a; Corbetta, Kincaide, and Shulman, 2002; Luck, Chelazzi, Hill- 
yard, and Desimone, 1997; Nobre, Sebestyen, Gitelman, Mesulam, Frackowiak, 
and Frith, 1997; Stein and Walsh, 1997), and in normal eye movement control 
(Bisley and Goldberg, 2003b; Yamasaki and Wurtz, 1991).

The relationship between impaired control of eye movements (that is, poor 
binocular control) and a reading deficit has been extensively investigated. Eye 
fixation in individuals with dyslexia has been shown to be unsteady when at-
templing to view small letters, and pursuit eye movements have been shown 
to be less smooth than in normal readers (Eden, Stein, Wood, and Wood, 
1994; Griffen, Christenson, Wesson, and Erickson, 1998; Stein, Riddell, and 
Fowler, 1988). One might expect that this unstable vision would lead to vi-
sual confusion and thus reading errors. Indeed, many of these individuals 
complain of letters and words moving around, merging and crossing over (Cor-
nelissen, Bradley, Fowler, and Stein, 1991). Although there is no disagreement 
about these observations, there are two opposing explanations of the causal 
relationship between eye movements and dyslexia. Some researchers have ar-
gued that abnormal eye movements cause reading difficulties (Pavlidis, 1991), 
while others argue that the abnormal eye movements are caused by difficul-
ties with comprehending the written language, or by difficulties in underlying 
attentional abilities (for reviews see Olson, 1991; Morris and Rayner, 1991).

Attentional mechanisms are not limited to the visual system. Evidence 
that there are covert attentional systems common to spatial orienting as well 
as orienting to language comes from studies of patients with parietal lesions. 
When these patients were required to monitor a stream of auditory information 
for a sound, they were slowed in their ability to orient toward a visual cue. 
The effects of the language task differed from the visual task in that they were 
bilateral rather than on the side opposite the lesion. Based on this study, 
Posner and Cohen (1987) suggested that visual orienting involves attentional 
mechanisms that are interconnected with those used for language processing. 
Similar results were found when testing a non-clinical sample (Posner, Sandson,
Dhawan, and Shulman, 1989).

Attention and reading

Covert attention has been shown to affect both spatial and temporal aspects of visual processing (Carrasco, McLean, Katz, and Frieder, 1998; Carrasco, Penpeci-Talgar, and Eckstein, 2000; Carrasco and McElree, 2001; Desimone, Chelazzi, Miller, and Duncan, 1995; Kinchla, 1992; Lu and Dosher, 1998; Nakayama and Mackeben, 1989; Palmer, 1994; Posner, 1980; Prinzmetal, Amirri, Allen, and Edwards, 1998; Reynolds and Desimone, 1999; Shiu and Pashler, 1994; Treue and Trujillo, 1999; Yeshurun and Carrasco, 1999). Physiological evidence provides support for an attentional effect on the quality of sensory representations (Desimone, Chelazzi, Miller, and Duncan, 1995; Reynolds and Desimone, 1999; Treue and Trujillo, 1999). Thus attentional deficits would be expected to affect various aspects of the reading process, and may be both a proximal and distal cause of dyslexia. That is, as a distal cause, poor attentional processes may hinder the development of the reading system. But also, as a proximal cause, poor attentional processes may directly impair the ability of the individuals with dyslexia to perceive and direct attention to the reading text in a way useful for processing.

Research examining the processes required for competent reading indicates that visual attention is a major contributor. For example, evidence suggests that sustained focused attention is required for the analysis of strings of letters or words during fixations (LaBerge and Brown, 1989), in addition to fast and accurate control of visual orienting between fixations (Inhoff, Pollatsek, Posner, and Rayner, 1989). Covert visual attention (attention without eye movements) has been linked with the control of saccades (rapid eye movements occurring between fixations). Specifically, research has shown that when attention is directed away from the location of a saccade target prior to eye movement, the latency of saccades is increased and the accuracy of the saccades is reduced.
Chapter 1: The nature of dyslexia

(Deubel and Schneider, 1996; Hoffman and Subramanian, 1995; Kowler, Anderson, Dosher, and Blaser, 1995). Parafoveal preview benefit, that is, the allocation of attention to useful information that will facilitate processing at subsequent fixations (Rayner, Murphy, Henderson, and Pollatsek, 1989), also requires that irrelevant or conflicting information be ignored. The size of the region from which useful information is obtained during an eye fixation is referred to as the perceptual span (McKonkie and Rayner, 1975). Several studies have shown that this span may vary according to the difficulty a reader has in processing foveal information (Henderson and Ferreira, 1990; Inhoff, Pollatsek, Posner, and Rayner, 1989; Schroyens, Vitu, Brysbaert, and d’Ydewalle, 1999), and in deciding the relevance of parafoveal information (Bertera and Rayner, 2000; Rayner and Fisher, 1987). Research also suggests that focal attention, rather than distributed attention, is necessary for the execution of an accurate saccade (McPeek, Malijkovic, and Nakayama, 1999).

Attentional processes are also necessary for the development of the reading system. Based on various models of reading, it appears that skilled reading develops gradually and requires an ability to shift attention from word-level units to letter-level units. This developmental pattern has been supported in a longitudinal study by Assink and Knuijt (2000). Furthermore, Wolford and Fowler (1984) proposed that poor readers do not develop this attentional ability and remain less flexible in reallocating attention to small components of a word. As a distal cause for dyslexia, this attentional deficit might result in fewer letter-to-sound associations being consolidated into memory, leading to poor pseudo-word reading.

Evidence for a role of visuo-spatial attention in dyslexia has been increasing. Children with dyslexia have been shown to have difficulties in maintaining their attentional focus (Faccoetti, Paganoni, Turatto, Marzola, and Mascetti, 2000b), while both adults and children with dyslexia have demonstrated orienting difficulties on spatial cueing tasks (Brannan and Williams, 1987; Faccoetti, Lorusso, Paganoni, Cattaneo, Galli, Umilta, and Mascetti, 2003; Faccoetti and Molteni,
Theories of dyslexia

2001; Facoetti, Turatto, Lorusso, and Mascetti, 2001; Roach, Edwards, and Hogben, 2004; Ruddock, 1991; Valdois, Gerard, Vanault, and Dugas, 1995) and visual search tasks (Buchholz and McKone, 2004; Casco and Prunetti, 1996; Heiervang and Hugdahl, 2003; Iles, Walsh, and Richardson, 2000; Vidyasagar, 1999). For example, Brannan and Williams (1987) and Facoetti et al. (2000b) found that, whereas a control group responded faster to targets that were preceded by a valid cue (80%) at target location, individuals with dyslexia were no faster when the target appeared at the cued location than when it appeared at an uncued location. The reduced sensitivity of the group with dyslexia suggested that the cues were not efficient at attracting attentional resources. Facoetti and Molteni (2001) have proposed that the orienting difficulties observed were the result of a diffusely distributed attentional system. These differences were specifically demonstrated when the children with dyslexia did not show an increase in response times for target detection with increasing target eccentricity (from central fixation). On visual search tasks, researchers have found that poor readers took longer than skilled readers to find complex, multi-featured targets amongst confusable distractors (Casco and Prunetti, 1996; Heiervang and Hugdahl, 2003; Iles et al., 2000; Vidyasagar and Pammer, 1999). Vidyasagar and Pammer (1999) suggest that this reflects a deficit in directing spatial attention. Vidyasagar (1999) further suggests that this deficit plays a direct role in the reading difficulties observed in dyslexia, since reading text requires controlled shifts of attention to different locations in space. Indeed, the level of attentional impairment has been shown to be related to the degree of reading impairment shown (e.g., Brannan and Williams, 1987; Buchholz and McKone, 2004; Vidyasagar and Pammer, 1999). These results are consistent with the idea that attentional processes constrain reading ability (see also Hari and Renvall, 2001; Hari, Renvall, and Tanskanen, 2001).

Evidence has also indicated an asymmetry of attentional distribution between the two visual fields in individuals with dyslexia, reflecting impairments specifically in right parietal cortex function. For example, in a study by Hari,
Renvall, and Tanskanen (2001), adults with dyslexia demonstrated a left visual field (LVF) mini-neglect for stimuli. Children with dyslexia have been shown to omit a greater number of targets presented in the LVF on a visual search task (Eden, Stein, and Wood, 1993; Fowler, Riddell, and Stein, 1990). More recently, children with dyslexia have been shown to have problems with target eccentricity when stimuli are projected to the LVF (Facoetti and Molteni, 2001; Facoetti, Turatto, Lorusso, and Mascetti, 2001), suggesting difficulties with left visual field inattention and right visual field over-distractibility.

Casco, Tressoldi, and Dellantonio (1998) reported a significant relationship between visual selective attention and reading performance, and recently, visual attention skills have been reported to make a contribution to reading performance which is independent of phonological skills (Valdois, Bosse, and Tainturier, 2004). Valdois, Bosse, Ans, Carbonnel, Zorman, David, and Pellat (2003) reported a case of surface dyslexia who showed specific difficulties with global processing of visual stimuli, compared to another case who showed phonological impairment but no visual impairment. They interpreted these findings as indicating two distinct forms of dyslexia, one due to impairment in visual attentional processes (surface dyslexia), and the other due to phonological impairment (phonological dyslexia). In the framework of the multi-trace model of reading, the visual attentional window (VAW) remains narrow, interfering with the global reading procedure and therefore the establishment of lexical knowledge. Thus, irregular word reading would be difficult. However, research also supports the hypothesis that poor readers with phonological difficulties have difficulty in analysing component parts of a word, that is, in reducing their attentional focus. Direct evidence has been presented by Marmurek (1988) (also see Zoccolotti, De Luca, Di Pace, Gasperini, Judica, and Spinelli, 2005) who found that, while good and poor readers are equally able to process words holistically, the poor readers were less able to constrain their attention on word composition. In the framework of the multi-trace model of reading, this might represent a difficulty in narrowing the VAW, leading to a
Theories of dyslexia

reduced ability in reading pseudo-words as seen in the phonological subtype of dyslexia. Thus, it is possible that the subtypes of dyslexia result either from different deficits in the same attentional process (e.g., adjusting the VAW), or deficits in different attentional processes (still to be determined).
Chapter 2

Rationale

Previous research has shown that word recognition deficits and other signs of childhood dyslexia (e.g., deficient knowledge of spelling-sound relationships and phonological awareness) persist from childhood into adulthood (e.g., Bruck, 1992; Felton et al., 1990). If visual deficits are major determinants of dyslexia, it would then be reasonable to expect them to also persist into adulthood. However, there is relatively little research examining attentional processes in adults with developmental dyslexia. For example, Hari, Valta, and Uutela (1999) reported a longer attentional blink (AB) for a group of adults with dyslexia, suggesting that this could represent a limitation in their attentional capacity compared to a control group. Hari and Renvall (2001) employed the line motion illusion to test the automatic attentional capture in adults with dyslexia. Their findings indicated a mild left mini-neglect which they suggest is an underlying attentional difficulty, rather than a direct cause of poor reading. An asymmetric distribution of attention between the two visual fields of adults with dyslexia has also been reported (Hari, Renvall, and Tanskanen, 2001). Iles, Walsh, and Richardson (2000) examined visual search performance in adults with dyslexia, and reported that conjunction visual search performance (a measure of selective attention) was poorer than in age-matched controls.
More recently, Buchholz and McKone (2004) examined contrast sensitivity (a measure of sensory function, specifically visual perception) and visual search performance in adults with phonological difficulties. It was found that while difficulties in both the functional areas were present, only those associated with selective attention showed a significant relationship to phonological difficulty.

2.1 Specificity of attentional deficit

Attention enables processing of information (within and/or between sensory modalities) through a variety of processes (which should not be considered mutually exclusive) including selection of items in space and time, vigilance, reduction of uncertainty, signal enhancement, modulation of processing and feature binding. These attentional processes may be defined within three central aspects: attentional control, the time course of attention and the representational basis for stimulus selection.

- **Attentional control:** Refers to the degree to which an individual’s attentional readiness (top-down or goal directed), or aspects of a stimulus independent of the perceptual goals (bottom-up or stimulus directed), capture attention. Typically, the goal-directed and stimulus-driven aspects of attentional control are considered separately, however these distinctions should be treated with caution. Some sort of goal state is always present in an observer, and the stimulus together with its brain representations always exert some influence, when processing the environment.

- **The time course of attention:** Refers to both movement through space and the selection of sequential events in time.

- **The representational basis for stimulus selection:** Refers to the direction of attention to regions of space (space based), or to pre-defined perceptual objects (object based).
Specificity of attentional deficit

Attentional processes may operate for both overt attention (where eye movements are allowed) and covert attention (when attention is deployed without eye movements) (Wu and Remington, 2003).

Overt selective visual attention refers to the process by which regions of space are selected for processing by an individual, and this usually involves eye movements. It has been argued that reading difficulties result from abnormal eye movements (Pavlidis, 1991). However, others argue that abnormal eye movements may themselves result from difficulties in language comprehension, or in underlying covert attentional abilities (for reviews see Morris and Rayner, 1991; Olson, 1991).

Recent evidence has indicated that reflexive and volitional shifts of spatial attention can be dissociated, both on tasks allowing eye movements (overt) and those in which eye movements are controlled (covert) (Hunt and Kingstone, 2003a,b). However, neuropsychological evidence has demonstrated a common brain area of functionality for covert attention and eye movements (Corbetta, Akbudak, Conturo, Snyder, Ollinger, Drury, Linenweber, Petersen, Raichle, Van Essen, and Schulman, 1998).

In addition to examining covert attentional processes, this thesis also examines attentional processing which allows eye movements. The relationships of performance on both covert and overt attentional tasks, to each other and, to the phonological processing abilities of the dyslexia cases is also examined.

Researchers have generally examined performance of their dyslexia participants on only one aspect of attention. Comparisons across studies then proves difficult since sampling methods can vary, as in inclusion criteria and subtype representation. Also, without testing the same individuals on several attentional tests, it remains unclear whether dyslexia represents a general attentional difficulty, or a more specific attentional deficit. In this thesis, the processes of attention outlined above are examined within a single sample of adults with dyslexia, all demonstrating phonological difficulties. This allows
direct comparisons across cases to be made and possibly enables core attentional deficits to be identified.

2.2 A case for case studies

Studies examining attentional function in dyslexia have generally relied on comparisons between a small group of individuals with dyslexia and a control group. These comparisons do not always consider the nature and distribution of individual differences within the groups. The distribution of scores is typically more variable for the dyslexia group than for the comparison group. As such, the scores of a small number of individuals who perform poorly can contribute unduly to overall mean differences between the groups (Cornelissen, Richardson, Mason, Fowler, and Stein, 1995; Hill, Bailey, Griffiths, and Snowling, 1999; McArthur and Bishop, 2001; Roach, Edwards, and Hogben, 2004; Tallal, 1980). In this thesis, both dyslexia group and individual dyslexia case to control group comparisons are made.

2.3 Aims

Three main aims of this research are:

- To build a profile of attentional abilities for several adult cases of dyslexia, in an attempt to determine if there is a specific attentional deficit related to dyslexia.

- To examine the relationship between performance on covert visual attentional tasks and other factors related to dyslexia. Specifically, overt visual attention, auditory memory, and phonological processes.

- To investigate how changes in methodology may account for the varying findings in attentional orienting by individuals with dyslexia.
Chapter 3

Screening and Assessment

All participants, recruited from the Australian National University (ANU) through flyer advertising, had successfully completed at least one unit at University. In some cases, a PhD had been attained. The experimental pool of adults with dyslexia (ADys) consisted of eight adults who had received a diagnosis of dyslexia as children, and currently met the criteria of dyslexia as determined by the Dyslexic Adult Screening Test (DAST: Fawcett and Nicolson, 1998). Phonological ability was further assessed using two testing procedures: non-word reading (Au and Lovegrove, 2001), and regular and irregular word and non-word reading and spelling (Bates and D’Oliveiro, 2003). Untimed reading and spelling abilities for real words were further evaluated using the Wide Range Achievement Test (WRAT-3: Wilkinson, 1993). Intellectual functioning was assessed using the Wechsler Adult Intelligence Scale-III (WAIS-III: Wechsler, 1997). Overt attentional abilities were assessed using the Test of Everyday Attention (TEA: Robertson, Ward, Ridgeway, and Nimmo-Smith, 1994).

All participants reported that they did not suffer an attention deficit disorder or mood disorder. This was substantiated directly with questions administered by a clinical psychologist (author of this thesis) based on DSM-IV crite-
ria (American Psychiatric Association, 2000), and the Brown Attention-Deficit Disorder Scales (BAdds: Brown, 1996), and indirectly through observation by the same trained clinician.

The participants had also successfully completed an optometric assessment within the last two years. All participants gave informed consent and the study was approved by the Human Research Ethics Committee at the ANU.

### 3.1 The modified t-test

Several methods have been developed to address the problems inherent in examining and reporting on case studies (see Crawford and Garthwaite, 2002, 2004; Crawford and Howell, 1998; Crawford, Garthwaite, Howell, and Gray, 2004), which recommend statistical adjustments to reduce the likelihood of Type I and Type II error. Throughout this thesis the modified t-test (Crawford and Garthwaite, 2002) has been employed to compare individual case scores with control group means. This test is defined by

$$t = \frac{X^* - X}{S\sqrt{\frac{n+1}{n}}}$$

where $X^*$ is the ADys case score, $X$ and $S$ are the mean and standard deviation, respectively, of scores in the control sample, and $n$ is the size of the control sample.

Under the null hypothesis, each dyslexia case is treated as an observation from a distribution with the same mean and variance as the control group. The difference from the one-sample t-test is that, rather than treat the control scores as population statistics, the control variance is adjusted to take into account the control sample size. This test has been shown to control Type I error rate appropriately, and is also robust even when the control data are severely skewed (Crawford and Garthwaite, 2005).
3.2 Psychometric Testing

The following tests provide measures which are referenced against normative data.

3.2.1 The Wide Range Achievement Test-3rd edition

The Wide Range Achievement Test-3rd edition (WRAT-3) provides an evaluation of reading and spelling abilities when no time constraints are given, and can be used with individuals from age 5 through to age 74. An individual is required to read single words across a page in the direction of normal text reading. Words for spelling are presented alone, then in a sentence and again alone. This provides the individual with a context, and avoids confusion for words which may sound alike but have different meanings and spellings. An individual’s results are expected to reflect their level of literacy given adequate schooling and a normal level of intelligence.

Scoring:

A standardised score \( \text{mean} = 100, \text{standard deviation (s.d.)} = 15 \) and percentile ranking is usually given. The norms are based on U.S. samples and show good validity and reliability (Singleton, 1999). A qualitative indication of school level of attainment may also be provided. Table 3.1 presents the control group mean (s.d.) scores on the WRAT subtest of reading and spelling, for each experiment presented in this thesis (Experiments 1-10), while Table 3.2 presents the dyslexia group mean (s.d.) scores together with the individual case scores.
Table 3.1: Control group performance on the Wide Range Achievement Test-3rd edition, as a function of experiment.

<table>
<thead>
<tr>
<th>Expt.</th>
<th>1 (n=12)</th>
<th>2 (n=11)</th>
<th>4 (n=10)</th>
<th>7 (n=11)</th>
<th>10 (n=11)</th>
<th>3 &amp; 5 (n=8)</th>
<th>6, 8 &amp; 9 (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading mean</td>
<td>110.75</td>
<td>110.55</td>
<td>110.40</td>
<td>110.36</td>
<td>110.10</td>
<td>109.50</td>
<td>109.63</td>
</tr>
<tr>
<td>s.d.</td>
<td>4.71</td>
<td>4.27</td>
<td>4.47</td>
<td>4.61</td>
<td>4.88</td>
<td>5.07</td>
<td>4.77</td>
</tr>
<tr>
<td>Spelling mean</td>
<td>112.92</td>
<td>113.82</td>
<td>113.40</td>
<td>114.00</td>
<td>112.70</td>
<td>114.00</td>
<td>112.81</td>
</tr>
<tr>
<td>s.d.</td>
<td>6.65</td>
<td>6.23</td>
<td>6.39</td>
<td>6.00</td>
<td>6.51</td>
<td>5.66</td>
<td>5.02</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, $p < 0.05$.

Table 3.2: Dyslexia group and individual ADys case performance on the Wide Range Achievement Test-3rd edition.

<table>
<thead>
<tr>
<th>Group mean (s.d.)</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading 89.25 (10.25)</td>
<td>94</td>
<td>105</td>
<td>76</td>
<td>81</td>
<td>90</td>
<td>79</td>
<td>103</td>
<td>86</td>
</tr>
<tr>
<td>Spelling 87.63 (11.11)</td>
<td>87</td>
<td>100</td>
<td>73</td>
<td>71</td>
<td>94</td>
<td>87</td>
<td>101</td>
<td>88</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, $p < 0.05$.

Analysis of data from the standardised literacy tests revealed impaired performance for all ADys cases except case SM and RM, when compared to the control group. With the exception of cases SW and GM, on both reading and spelling, and JM on reading, all cases were within the normal range on these tests, that is, within one standard deviation of the standardised mean.
3.2.2 Dyslexia Adult Screening Test

Often adults with dyslexia perform within age levels according to their WRAT results, but tend to read slowly and laboriously. The Dyslexia Adult Screening Test (DAST) is a standardised screening instrument for the identification of dyslexia in adults (>17 years of age), and requires the individual to process and respond to the information contained in its subtests in a given time limit, or as quickly as possible. The test battery includes 3 tests of literacy attainment and 8 diagnostic tests. An overview of the tests contained in the DAST with a brief description of the areas each evaluates, is presented in Table 3.3.

The attainment tests provide information about whether an adult continues to have difficulty with reading, writing and spelling, but do not give an indication as to why this is so. The diagnostic tests examine a range of skills which are known to be affected in dyslexia, and examination of the results of these tests can provide useful information as to why a literacy difficulty is present, and which skills require support and training.

Scoring:

Taken together, the 11 scores obtained provide an overall At Risk Quotient (ARQ: range = +1 to -3) for dyslexia, with more negative scores indicating a greater risk of dyslexia.

Postural Stability was not tested in this study. Figure 3.1 provides the profile of each ADys case for the remaining ten subtests, together with the ARQ. Individuals with an ARQ ≥ 0.7 were included as it has been recently reported that this level provides a better hit rate for those who have reported reading difficulties (Harrison and Nichols, 2005).
Table 3.3: Subtests of the Dyslexic Adult Screening Test.

<table>
<thead>
<tr>
<th>Tests of Attainment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Minute Reading (OMR)</td>
<td>Evaluates the number of words an individual can read in one minute. This subtest combines reading fluency and accuracy.</td>
</tr>
<tr>
<td>Two Minute Spelling (TMS)</td>
<td>Each word to be spelled is given once, with the next word given immediately the individual finishes the current one. This subtest combines spelling fluency and accuracy.</td>
</tr>
<tr>
<td>One Minute Writing (OMW)</td>
<td>Evaluates speed of copying text. Together with the spelling test score, it is possible to determine an individual’s thinking speed for spelling.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagnostic Tests</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid Naming (RN)</td>
<td>Individuals name pictures as quickly as possible.</td>
</tr>
<tr>
<td>Postural Stability (PoSt)</td>
<td>Provides an index of balance ability when posture is disturbed by a controlled push in the back.</td>
</tr>
<tr>
<td>Phonemic Segmentation (PS)</td>
<td>This provides a direct measure of “Phonological Awareness” (Adams, 1990), and does not require the participant to read or write. It examines the ability to break a word into its constituent sounds, and manipulate those sounds. Spoonerisms are included as a more complex test of phonological skill.</td>
</tr>
<tr>
<td>Backwards Digit Span (BS)</td>
<td>Test of working memory.</td>
</tr>
<tr>
<td>Nonsense Passage Reading (NP)</td>
<td>Examines the ability to read nonsense words and real words in a nonsense passage, as quickly as possible.</td>
</tr>
<tr>
<td>Non-verbal Reasoning (NVR)</td>
<td>Provides a ‘rough’ measure of intelligence.</td>
</tr>
<tr>
<td>Verbal (VF) and Semantic Fluency (SF)</td>
<td>For verbal fluency, individuals are required to name as many words as possible in one minute, using a given letter of the alphabet. Semantic fluency requires naming as many items as possible in one minute, within a category.</td>
</tr>
</tbody>
</table>
Figure 3.1: DAST profile for each dyslexia case for 10 subtests. (Note: Postural Stability was not tested. See Table 3.3 for key to subtests.)
It can be seen that while these profiles varied, phonological difficulties were shown by all ADys cases, as demonstrated by decreased ability on the Phonemic Segmentation task. Other subtests considered to tap phonological skills are nonsense passage reading and rapid naming. Difficulty reading nonsense words (specifically) indicates a difficulty in breaking the written word into chunks that can be articulated. This is consistent with the findings of previous studies of adults with dyslexia (e.g., Bruck, 1992; Brunswick, McCrory, Price, Frith, and Frith, 1999; Fawcett and Nicolson, 1995a; Felton, Naylor, and Wood, 1990; Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak, and Frith, 1996) where phonological processing difficulties persisted even when literacy skills were in the average range (e.g., cases SM and RM). This may depend on ADys literacy training and the ability to use an orthographic strategy (sight vocabulary). All cases (except TM and SM) show a profile of good semantic fluency together with poor verbal fluency. It has been suggested that this may be characteristic of dyslexia (Frith, 1995). SM showed a reverse pattern with good verbal fluency and poor semantic fluency, and TM did not perform poorly on either of these tasks.

3.2.3 The Wechsler Adult Intelligence Scale-III

The Wechsler Adult Intelligence Scale-III (WAIS-III) comprises a four-level framework. An overall measure of intellectual functioning (Full-scale IQ) is calculated using all the subtests of the WAIS-III, while a verbal IQ measure uses only verbal subtest scores and a performance IQ measures only performance subtest scores. The verbal and performance scales are further divided into a pair of factor indices each (see Fig. 3.2).

- **Verbal Comprehension Index:** Evaluates ability to answer oral questions about facts and word meanings, as well as the ability to verbally express ideas.
- **Working Memory Index**: Evaluates the ability to manipulate numbers and/or letters in a sequential fashion, when these are presented orally, and requires a good attention span.

- **Perceptual Organisation Index**: Evaluates the ability to integrate visual stimuli, and solve abstract problems which are not school taught.

- **Processing Speed Index**: Evaluates both speed of thinking and motor speed.

Figure 3.2: WAIS-III framework. (See Table 3.4 for key to tests.)

The WAIS-III evaluates a variety of abilities and skills that are considered to be part of intelligence, and provides an estimate of intellectual functioning. An overview of the unique abilities tested by each subtest may be found in Table 3.4.
Table 3.4: Unique abilities tested by verbal and performance subtests of the WAIS-III.

<table>
<thead>
<tr>
<th>Verbal Tests</th>
<th>Unique Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vocabulary (V)</td>
<td>Language development and word knowledge</td>
</tr>
<tr>
<td>Similarities (S)</td>
<td>Abstract thought</td>
</tr>
<tr>
<td>Digit Span (DS)</td>
<td>Immediate recall</td>
</tr>
<tr>
<td>Information (I)</td>
<td>General knowledge</td>
</tr>
<tr>
<td>Comprehension (C)</td>
<td>Social judgement and knowledge of social standards of behaviour</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Tests</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture Completion (PC)</td>
<td>Visual recognition, abstract reasoning and visual integration</td>
</tr>
<tr>
<td>Digit Symbol Coding (DSC)</td>
<td>Psychomotor speed (speed of making a motor response based on a mental decision)</td>
</tr>
<tr>
<td>Block Design (BD)</td>
<td>Formation of non-verbal concepts; ability to analyse component parts of a pattern</td>
</tr>
<tr>
<td>Matrix Reasoning (MR)</td>
<td>Problem solving (without time constraints)</td>
</tr>
<tr>
<td>Picture Arrangement (PA)</td>
<td>Temporal sequencing</td>
</tr>
<tr>
<td>Symbol Search (SS)</td>
<td>Speed of visual search</td>
</tr>
</tbody>
</table>

**Scoring**

Scores for IQ and index measures have a mean of 100 and a standard deviation of 15. Qualitatively, scores below 80 would be concerning. The Full-scale IQ provides a good overall view of an individual’s performance, however, human cognitive functioning is complex and therefore different abilities should be examined separately. Tables 3.5 and 3.6 provide a summary of scores for the control group and individuals with dyslexia.
Table 3.5: Control group age and cognitive function.

<table>
<thead>
<tr>
<th>Expt.</th>
<th>1 (n=12)</th>
<th>2 (n=11)</th>
<th>4 (n=11)</th>
<th>7 (n=8)</th>
<th>10 (n=10)</th>
<th>3 &amp; 5 (n=16)</th>
<th>6, 8 &amp; 9 (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age <strong>mean</strong></td>
<td>33.00</td>
<td>31.18</td>
<td>35.90</td>
<td>31.64</td>
<td>34.50</td>
<td>31.13</td>
<td>31.25</td>
</tr>
<tr>
<td></td>
<td>8.89</td>
<td>8.27</td>
<td>9.67</td>
<td>7.97</td>
<td>7.79</td>
<td>8.87</td>
<td>7.47</td>
</tr>
<tr>
<td>VIQ <strong>mean</strong></td>
<td>122.17</td>
<td>121.18</td>
<td>121.80</td>
<td>122.18</td>
<td>118.19</td>
<td>120.09</td>
<td>120.75</td>
</tr>
<tr>
<td></td>
<td>9.63</td>
<td>10.28</td>
<td>10.62</td>
<td>8.64</td>
<td>10.58</td>
<td>10.70</td>
<td>8.82</td>
</tr>
<tr>
<td>PIQ <strong>mean</strong></td>
<td>121.83</td>
<td>123.64</td>
<td>124.44</td>
<td>123.27</td>
<td>118.88</td>
<td>121.50</td>
<td>121.88</td>
</tr>
<tr>
<td></td>
<td>9.17</td>
<td>8.58</td>
<td>8.64</td>
<td>9.27</td>
<td>10.84</td>
<td>10.09</td>
<td>8.67</td>
</tr>
<tr>
<td>FSIQ <strong>mean</strong></td>
<td>124.25</td>
<td>124.91</td>
<td>125.70</td>
<td>125.36</td>
<td>120.63</td>
<td>123.00</td>
<td>123.44</td>
</tr>
<tr>
<td></td>
<td>9.82</td>
<td>10.15</td>
<td>10.34</td>
<td>9.30</td>
<td>11.21</td>
<td>11.06</td>
<td>9.32</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, \( p < 0.05 \).

Table 3.6: Dyslexia group and individual case age and cognitive function.

<table>
<thead>
<tr>
<th>Group mean (s.d.)</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>31.30 (13.20)</td>
<td>24</td>
<td>27</td>
<td>45</td>
<td>51</td>
<td>25</td>
<td>32</td>
<td>20</td>
</tr>
<tr>
<td>VIQ</td>
<td>113.90 (6.50)</td>
<td>113</td>
<td>114</td>
<td>120</td>
<td>112</td>
<td>113</td>
<td>101</td>
<td>123</td>
</tr>
<tr>
<td>PIQ</td>
<td>123.30 (6.50)</td>
<td>125</td>
<td>127</td>
<td>128</td>
<td>123</td>
<td>118</td>
<td>132</td>
<td>138</td>
</tr>
<tr>
<td>FSIQ</td>
<td>127.40 (13.30)</td>
<td>121</td>
<td>128</td>
<td>127</td>
<td>120</td>
<td>117</td>
<td>114</td>
<td>134</td>
</tr>
<tr>
<td><strong>Index</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VCI</td>
<td>118.00 (5.24)</td>
<td>118</td>
<td>122</td>
<td>110</td>
<td>120</td>
<td>126</td>
<td>116</td>
<td>112</td>
</tr>
<tr>
<td>WMI</td>
<td>100.88 (13.55)</td>
<td>102</td>
<td>111</td>
<td>102</td>
<td><strong>84</strong></td>
<td><strong>99</strong></td>
<td><strong>80</strong></td>
<td>108</td>
</tr>
<tr>
<td>POI</td>
<td>118.75 (12.01)</td>
<td>109</td>
<td>128</td>
<td>133</td>
<td>105</td>
<td>123</td>
<td>101</td>
<td>123</td>
</tr>
<tr>
<td>PSI</td>
<td>108.75 (11.89)</td>
<td>125</td>
<td>123</td>
<td>117</td>
<td><strong>96</strong></td>
<td><strong>99</strong></td>
<td>106</td>
<td>103</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, \( p < 0.05 \).
As shown in Table 3.6, no significant differences were found between each individual ADys case and the control group on measures of Verbal IQ, Performance IQ and Full-scale IQ. Performance IQ was significantly higher than Verbal IQ for all ADys cases (except SW, TC and TM), a finding which is often reported for individuals with learning disabilities. Cases GM, TC and JM also presented with working memory difficulties, which have been implicated in dyslexia (e.g., De Jong, 1998; Gathercole and Baddeley, 1993; Shankweiler, Crain, Brady, and Macaruso, 1992). Cases GM, TC and TM presented with difficulties in processing speed.

Motor difficulties have frequently been reported in individuals with dyslexia (Fawcett and Nicolson, 1995b; Fawcett, Nicolson, and Maclagan, 2001; Wolff, 2002; Wolff, Michel, Ovrut, and Drake, 1990), with an estimated 30 - 50% of the dyslexia population being affected. Although a causal link between motor difficulties and phonological processing is unlikely (Ramus et al., 2003a), the methodologies used throughout this thesis allow any such possible confounds to be removed from the response time measures.

3.2.4 Test of Everyday Attention

The Test of Everyday Attention (TEA) evaluates abilities associated with various aspects of attention and concentration. Figure 3.3 illustrates the relationship between the subtests and the different attentional factors measured by the TEA.

- **Visual selective attention/speed:** This refers to the ability to select a given item/object from amongst competing objects. Speed of processing may play a part as all subtests are timed. Individuals with a deficit in this area may have difficulty filling in forms, finding a phone number in a directory or selecting a particular word in text.
• **Attentional switching:** This refers to the ability to switch attention flexibly, that is, the ability to change from one topic to another.

• **Sustained attention:** This refers to the ability to maintain and sustain concentration and attention on tasks in which repetitive stimuli are presented without external cues. Individuals with difficulties in this area may lose concentration while reading, watching TV and when talking with friends or family. Note: The TEA subtest *Telephone Search while Counting* also tests an individual’s ability to divide their attention (i.e., to do more than one thing at a time). Poor performance on this subtest alone may indicate difficulties responding to competing demands.

• **Auditory-verbal working memory:** This refers to the ability to manipulate and sequence auditory-verbal information in working memory (also assessed by WAIS-III, Backward Digit Span subtest). The TEA subtests for this measure also contain an auditory selective attention component.

![Diagram](image.png)

Figure 3.3: TEA framework.

**Scoring:**

Scaled scores (mean = 10, standard deviation = 3) and/or percentile ranking is provided for each subtest of the TEA.
Table 3.7: Control group (n=16) and dyslexia case scaled scores on TEA.

<table>
<thead>
<tr>
<th>Factor 1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Control mean (s.d.)</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>12.55 (1.51)</td>
<td>16</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>14</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>TS</td>
<td>13.55 (3.01)</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>7</td>
<td>6</td>
<td>12</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Factor 2&lt;sup&gt;b&lt;/sup&gt;VE</td>
<td>12.00 (1.79)</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>9</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Factor 3&lt;sup&gt;c&lt;/sup&gt;TSC</td>
<td>12.00 (2.28)</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>9</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>L</td>
<td>12.27 (0.90)</td>
<td>13</td>
<td>13</td>
<td>6</td>
<td>12</td>
<td>5</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Factor 4&lt;sup&gt;d&lt;/sup&gt;ECD</td>
<td>11.82 (1.54)</td>
<td>13</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>ECR</td>
<td>13.09 (2.07)</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>

<sup>a</sup> Visual Selective Attention: MS1 = Map Search, TS = Telephone Search

<sup>b</sup> Attentional Switching: VE = Visual Elevator

<sup>c</sup> Sustained Attention: TSC = Telephone Search while Counting, L = Lottery

<sup>d</sup> Auditory-verbal Working Memory: ECD = Elevator Counting with Distraction, ECR = Elevator Counting with Reversal

Note that digits in **bold** indicate a significant difference to the control group, \( p < 0.05 \).

As shown in Table 3.7, no significant differences were found between each individual ADys case and the control group on the Attentional Switching factor. Cases GP, SM and TM showed comparable performance to the control group for all attentional factors. Cases GM, TC, JM and RM demonstrated poorer performance on on the Auditory-verbal Working Memory factor. As mentioned previously, working memory has been implicated in dyslexia (e.g., De Jong, 1998; Gathercole and Baddeley, 1993; Shankweiler et al., 1992), and is examined in Chapter 8. While cases SW and GM appeared to show some difficulty, for Sustained Attention and Visual Selective Attention respectively, the
differences in subtest scores prevents valid interpretation of the results. Case TC also demonstrated poor performance on the Visual Selective Attention and Sustained Attention factors. This suggests a possible general attention deficit which is further examined in the following section.

3.2.5 Brown Attention-Deficit Disorder Scales

Since attentive processes were examined, it was important to remove possible elements which could confound the interpretation of findings. For example, an estimated 20 - 50% clinical overlap between dyslexia and attention-deficit hyperactivity disorder (ADHD) has been reported (Lambert and Sandoval, 1980; Willcutt and Pennington, 2000). Thus, to determine if attentive processes are deficient in dyslexia alone, only participants who do not meet criteria for diagnosis of ADHD and related disorders were included in the participant sample.

The BADDS (Brown, 1996) are designed for self-report from adolescents and adults of symptoms indicative of a possible Attention-Deficit Disorder. The scales assess symptoms recognized in the American Psychiatric Association diagnostic system: DSM-IV, as well as others which have been reported by individuals with ADD.

The scales are comprised of 40 interrelated cognitive and affective symptoms grouped into five clusters:

- **Organising and activating to work**: Evaluates excessive difficulty in getting organised and getting started on work-related activities, as well as daily routines.

- **Sustaining attention and concentration**: Evaluates ability to sustain attention to work-related tasks.

- **Sustaining energy and effort**: Evaluates problems in consistency of effort and energy for work-related tasks.
• **Managing affective interference:** Assesses difficulties with mood and sensitivity to criticism.

• **Utilising “working memory” and accessing recall:** Evaluates forgetfulness in daily routines and ability to recall learned material.

**Scoring:**

The individual reports how often they have experienced each item according to a Likert scale where 0 = never; 1 = once a week; 2 = twice a week; 3 = almost daily.

Cluster scores and a total score are calculated (T-scores may be obtained: standardised \( \text{mean} = 50, \ s.d. = 10 \)). A total score of 50 is recommended as a clinical cut-off score, indicating a significant possibility that the individual will meet diagnostic criteria for ADD. In these cases, further evaluation by a trained clinician is necessary. ADD may be ruled out if some other diagnosis can clearly explain the symptoms.

According to the published norms of this test, a total score of above 55 is thought to indicate a diagnosis of ‘ADD highly probable’. As seen in Table 3.8, the control group scores fell below this clinical cut-off (although it should be noted that one control case scored a total of 58). An examination of the cluster scores revealed that ADys case TC scored high on activation, attention and affect, and case GP on attention and memory. These two cases also scored above the clinical cut-off. While all other ADys cases scored below the clinical cutoff, as a cautionary measure each ADys (together with the single control participant) was further assessed using the Brown Diagnostic Form. This provides an evaluation based on the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV American Psychiatric Association, 2000) AD/HD criteria, together with other diagnostic criteria for ADD. All cases, including TC and GP, did not meet the criteria for a diagnosis of an attentional deficit disorder.
Table 3.8: Control group (mean (s.d.)) and dyslexia case T-scores on BADDS.

<table>
<thead>
<tr>
<th></th>
<th>Control n=8</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activation</td>
<td>51.18 (3.06)</td>
<td>51</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>58</td>
<td>53</td>
<td>&lt; 50</td>
<td>53</td>
</tr>
<tr>
<td><strong>Factor 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td>51.64 (3.67)</td>
<td>60</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>62</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td><strong>Factor 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effort</td>
<td>50.73 (2.41)</td>
<td>53</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>53</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td><strong>Factor 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affect</td>
<td>50.91 (2.03)</td>
<td>&lt; 50</td>
<td>53</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>58</td>
<td>53</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td><strong>Factor 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Memory</td>
<td>52.27 (4.67)</td>
<td>61</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>51</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>48.82 (5.25)</td>
<td>58</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>58</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

### 3.3 Reading and Spelling

The nature of the reading and spelling difficulties shown by the ADys cases was further evaluated. The following tests are not standardised but allow a comparison to be made between the ADys cases and the control group.

#### 3.3.1 Test of non-word reading

Hatcher, Snowling, and Griffiths (2002) examined cognitive assessment in adults with dyslexia and reported that while there was no difference compared to that of the control group on general cognitive ability, clear difficulties were observed on spelling and non-word reading. While the DAST provides some indication of ability on these skills, further evaluation was conducted.
Non-words are meaningless, novel letter strings that have conventional spelling patterns. Non-word reading accuracy provides an index of the success with which unfamiliar words can be read aloud using phonological decoding strategies, that is, knowledge of letter-sound relationships. In the first five experiments, non-word reading was evaluated using a list of sixty non-words (see Appendix A1) developed by Au and Lovegrove (2001), where thirty were selected from Castles and Coltheart (1993), and thirty were selected from the Woodcock’s Reading Mastery Tests - Revised (Woodcock, 1987) and Woodcock Language Proficiency Battery Test Book (Woodcock, 1984). The mean number of correct non-words read for control participants across the first five experiments (n = 15), the dyslexia group (n=8), and each dyslexia case are presented in Table 3.9. As can be seen, all the ADys cases showed significantly poorer ability to read non-words compared to the control group.

Table 3.9: Control and dyslexia group, and dyslexia case scores on non-word reading.

<table>
<thead>
<tr>
<th></th>
<th>Control n=15</th>
<th>ADys n=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score /60 s.d.</td>
<td>56.67/2.77</td>
<td><strong>33.43/11.77</strong></td>
</tr>
<tr>
<td>GP</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>SM</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>SW</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>GM</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>TC</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>JM</td>
<td>37</td>
<td>45</td>
</tr>
<tr>
<td>RM</td>
<td>45</td>
<td>34</td>
</tr>
<tr>
<td>TM</td>
<td>34</td>
<td>34</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, $p < 0.05$.

### 3.3.2 Test of reading and spelling

Given the complex nature of reading, an additional five tests were employed to assess reading. These tests were developed according to the dual route cascaded (DRC) computational model of reading (see Bates, Castles, Coltheart, Gillespie, Wright, and Martin, 2004).
• **Reading Tests:** Regular word, irregular word and non-word reading was assessed using a 120-word extended version of tests developed by Castles and Coltheart (1993). The developers propose that irregular words provide a test of lexical reading, since the nonlexical route would sound them out incorrectly. Nonwords however, are not found within a lexicon but can be sounded out by the nonlexical route. Regular words may be read using either route (see Appendix B1).

• **Spelling Tests:** Oral spelling of words was tested using 18 regular and 18 irregular words (see Appendix B2). Nonlexical spelling was tested by presenting the irregular words for a second time, and requiring participants to regularise the spelling, i.e., “Spell it as it sounds” (see Appendix B3).

Performance of a control group (Experiment 4), dyslexia group and individual ADys cases are presented in Table 3.10. As can be seen, compared to the control group, cases SW, GM and RM demonstrated poorer regular word reading: All ADys cases demonstrated poorer reading and spelling for both irregular words and nonwords. Only cases GP, JM and TM were comparable to the control group on spelling regular words.

Variations in exception (irregular) word reading has been linked to reading experience, reflecting the requirement for print exposure to learn the inconsistencies of the written language (see Snowling, 2000). Thus, defining subtype classification of the ADys cases in this study was not considered applicable given that some cases may have fit a mixed category simply due to reduced print exposure since childhood, compared to other cases (and this is not testable). Therefore, the ADys cases are simply referred to as demonstrating phonological difficulties.
Table 3.10: Control and dyslexia group, and dyslexia case scores on reading and spelling tests.

<table>
<thead>
<tr>
<th></th>
<th>Control n=10</th>
<th>ADys n=8</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Reading</em> /40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular s.d.</td>
<td>39.4</td>
<td>0.8</td>
<td>36.5</td>
<td>37</td>
<td>38</td>
<td>36</td>
<td>36</td>
<td>37</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td>Irregular s.d.</td>
<td>39.2</td>
<td>1.0</td>
<td>32.8</td>
<td>34</td>
<td>35</td>
<td>29</td>
<td>33</td>
<td>30</td>
<td>35</td>
<td>34</td>
</tr>
<tr>
<td>Nonword s.d.</td>
<td>38.1</td>
<td>1.5</td>
<td>23.6</td>
<td>27</td>
<td>25</td>
<td>16</td>
<td>23</td>
<td>20</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td><em>Spelling</em> /18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular s.d.</td>
<td>17.8</td>
<td>0.4</td>
<td>15.3</td>
<td>17</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>17</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>Irregular s.d.</td>
<td>17.3</td>
<td>0.7</td>
<td>10.9</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>7</td>
<td>14</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Nonword s.d.</td>
<td>16.7</td>
<td>1.6</td>
<td>6.0</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>8</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, \( p < 0.05 \).

### 3.4 Visual Acuity

#### 3.4.1 Landolt ring-gap detection

This task examined the ability to resolve fine spatial information, providing a measure of ventral pathway sensitivity. The Landolt ring-gap detection display stimulus consisted of a broken circle (C) oriented randomly such that the gap occurred in one of four positions; to the right, left, up or down (Riggs, 1965). The circle subtended a visual angle of 0.57° situated within a square subtending
a 2.8° angle. This square was centrally positioned on an otherwise black screen. The C was presented for 72 msec, and a fixation dot in the middle of the screen remained visible throughout the trials. Example test displays are shown in Figure 3.4. Participants were required to indicate the orientation of the gap by pressing a corresponding key. The dependent measure was the minimum gap size required for accurate detection. This threshold was determined by the PEST staircase procedure (Taylor and Creelman, 1967) beginning with a gap of 20° arc (0.11° visual angle) on the first trial. A total of 14 practice trials with a constant gap size (20°) were given, followed by three blocks of test trials. No zero gap trials were included.

![Figure 3.4: Landolt-C test of visual acuity.](image)

The thresholds of ring gap detection, measured in degrees of visual arc, were determined. Repeated measures ANOVA indicated no main effect of reading group: dyslexia group ($M = 0.040, s.d. = 0.007$), control group ($M = 0.042, s.d. = 0.005$). Thus, performance of the dyslexia group on this visual acuity test was normal.
Chapter 4

Visual selective attention

Visual selective attention acts as a gatekeeper, passing a subset of relevant stimuli for further processing in a limited capacity system. A large percentage of research on attention has focussed specifically on this area. According to the biased competition model (Desimone, Chelazzi, Miller, and Duncan, 1995; Luck, Chelazzi, Hillyard, and Desimone, 1997), stimulus selection depends on the relative contributions of bottom-up, or stimulus-driven mechanisms of attention, and top-down or goal-directed mechanisms. Bottom-up mechanisms appear to be largely automatic processes which shift attention to potentially important visual features (e.g., colour or motion). In contrast, top-down mechanisms depend upon selecting objects which have relevance to a current behaviour, that is, in biasing attention toward a specific item (e.g., making a key press when a predetermined stimulus appears) (Desimone, Chelazzi, Miller, and Duncan, 1995; Egeth and Yantis, 1997; Kastner, DeWeerd, Desimone, and Ungerleider, 1998). The most widely used method for examining each of these mechanisms has been visual search.

In a typical visual search experiment, observers are presented with a display containing a number of items. They are required to indicate, as rapidly as possible while avoiding errors, whether a prespecified stimulus (the target) is
present among an array of other stimuli (the distractors), the number of which can vary in quantity. In a standard experiment, stimuli are presented for an unlimited time and changes in response time (RT) as a function of set size provides the measure of search performance.

The visual search paradigm is valuable because performance varies in a systematic way with the nature of the stimuli. When the target differs from distractors by a unique feature (e.g., red target, green distractor), it has been repeatedly demonstrated that the time required by neurologically normal (NN) individuals to detect the presence of a target is independent of the number of stimuli that are presented (Nakayama and Mackeben, 1989; Treisman and Gelade, 1980). According to Treisman and her colleagues, these observations indicate that detection of a feature target is performed by a spatially parallel process, with pre-attentive processing of visually distinctive features (bottom-up influences), and does not involve the selection of an individual stimulus by visuospatial attention.

It has long been argued, and research suggests, that spatial attention is required at the point in bottom-up processing where simple sensory features are combined (Treisman, 1990, 1996, 1998; Treisman and Gelade, 1980; Treisman and Sato, 1990). To distinguish conjunction targets from distractors, combinations of features constituting the items need to be considered. For example, in a typical conjunction search task, if the target is a red horizontal bar, one set of distractors consists of red vertical bars and another of green horizontal bars. In this way, the target cannot be distinguished from the distractors by a single unique feature, since it shares colour with some and orientation with others. Results of NN participants in such a conjunction task have shown linearly increasing RTs with an increasing number of distractors displayed. Visual search rate is usually reported at about 20 - 30 msec per item (Horowitz and Wolfe, 1998; Pashler, 1987; Treisman, 1990). Treisman developed her Feature Integration Theory based on these findings. According to this theory, search is inefficient because it requires sequential examination of each item location. To
correctly perceive a conjunction of features, visuospatial attention (top-down attentional processes) needs to be focused at the particular location of the item to bind the features and decide whether the resulting representation is the target.

Wolfe (1994) proposed a refined model of visual search called “Guided Search”. The basic idea is that a serial visual attention stage can be guided by a parallel feature-computation stage. The latter stage represents items in feature maps, and then assigns priorities according to (a) significant feature differences from neighbours, which receive high bottom-up activation and (b) target similarity, which receive high top-down activation. In this way, a priority map for search is generated to guide serial search. However, due to noise from this parallel processing, the target may not always receive the highest activation values. Once a location is visited, the priority it was given is canceled to prevent revisiting that is inhibition of return (IOR) (Klein, 2000). (Note: several researchers have shown that observing IOR depends on methodology (e.g., Reppa and Leek, 2003; Wright and Richard, 2000)).

Metaphorically, the serial process of attention has often been referred to as a “spotlight” or “zoom lens”, suggesting that the attentional focus and processing capacity are spread over multiple objects, with attentional load being critical in determining the size of the attentional focus (Lavie and Cox, 1996; Lavie and Tsal, 1994; Rees, Frith, and Lavie, 1997). It has been suggested that scaling of the size and resolution of attentional focus may occur either during the search process (Grossberg, Mingolla, and Ross, 1994; Lamb and Yund, 1996), or prior to search when the target is known (Greenwood and Parasuraman, 1999; Luo, Greenwood, and Parasuraman, 2001). Thus, performance on a serial task reflects ability to scale and move the attentional focus.

Several studies have examined visual search in children (Casco and Prunetti, 1996; Vidyasagar, 1999) and adults (Iles, Walsh, and Richardson, 2000) with developmental dyslexia. The general finding is that, as a group, the individuals with dyslexia take longer than skilled readers to find complex, multi-
Chapter 4: Visual selective attention

featured targets amongst confusable distractors (Casco and Prunetti, 1996; Heiervang and Hugdahl, 2003; Iles et al., 2000; Vidyasagar and Pammer, 1999). Vidyasagar and Pammer (1999) suggest that this reflects a deficit in directing spatial attention. Vidyasagar (1999) further suggests that this deficit plays a direct role in the reading difficulties observed in dyslexia, since reading text requires controlled shifts of attention to different locations in space.

4.1 Experiment 1

In this study, both a standard visual search task (RT) and one where stimuli were presented for a limited time (accuracy) were used to examine performance of adults with dyslexia. The accuracy version of the visual search task tests performance more rigorously, by excluding confounding factors usually present in the standard version. First, the stimulus array is presented such that total exposure time was equal to the number of items multiplied by 30 msec. This essentially removes eye movements (the maximum exposure being 330 msec = at most one eye movement) but is still sufficient to allow normal readers to move attention across items in conjunction searches with a target condition (Horowitz and Wolfe, 1998; Pashler, 1987; Treisman and Gelade, 1980; Treisman and Sato, 1990; Wolfe, Alvarez, and Horowitz, 2000). Any deficit in attentional mechanisms is then reflected in decreased accuracy as set size increases. The accuracy measure also removes the confounding effect of poor motor control which is commonly seen in dyslexia (Fawcett and Nicolson, 1995b; Fawcett, Nicolson, and Maclagan, 2001; Wolff, 2002; Wolff, Michel, Ovrut, and Drake, 1990) and is thus inherent in response time measures of their visual search performance. It has recently been shown that individuals with dyslexia are impaired on this version of the visual search task compared to normal readers (Buchholz, 1999; Buchholz and McKone, 2004).

Since higher level attentional function relies on cortical function, which in turn is potentially more sensitive to learning, adults with dyslexia may
not show deficits on this task. They may have been able to overcome their childhood difficulty with attentional shifts. If this were the case, then normal performance might be obtained on the conjunction visual search task. Carryover of a childhood attentional deficit into adulthood would predict that deficits would still be apparent on this task.

4.1.1 Method

Participants

Eight adults with dyslexia (ADys) participated in this experiment. The control group consisted of twelve adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.

Stimuli and procedure

Participants were seated approximately 90 cm from the computer monitor. The tasks were generated using an IBM PC (386) with a 17.8 msec refresh rate. To examine basic visual processing, without inducing reading strategies, a visual search task was employed in which the simple features of target items (rectangles) in the display were orientation (horizontal or vertical) and size (large: $0.2^\circ \times 0.4^\circ$ of visual angle or small: $0.1^\circ \times 0.2^\circ$ of visual angle). An example stimulus display is presented in Figure 4.1.

The number of items in the display (set size) varied across 3 levels (5, 7, and 11 items) and were positioned at randomly chosen locations on an invisible grid consisting of 24 locations (approx. $2.28^\circ \times 3.28^\circ$ of visual angle). The target appeared in the stimulus array in a random 50% of the trials. On each trial, the participant was shown the target to be detected by presenting it in the centre of the screen for 1000 msec. After a delay of 500 msec (to minimize retinal visual persistence of the target), the stimulus array was presented and remained on screen until the participant used a keyboard press to respond either target present or absent. Trials were organised into blocks consisting of
72 trials each. In each block, the target item was a small horizontal rectangle in 50% of trials and a small vertical rectangle in the other 50% of trials.

![Figure 4.1: Visual search: Example of a target present trial with six distractors. (Parallel search is required in A, and serial search in B.)](image)

To examine parallel search, two blocks of 72 trials were presented for each target detection task. Response times for the detection of a target element, distinguished from distractor elements by orientation or size were measured. To examine serial search, two visual search experiments (each with two blocks of 72 trials) were carried out. Both experiments combined orientation and size features of the target (either small-horizontal or small-vertical). In the first experiment, a standard procedure was employed where set displays remained on screen until participants responded. The measure of performance was response time (accuracy was also determined and found to be constant across set sizes). In the second experiment, time of set duration was determined as
30 msec per item in the set (i.e., 150 msec for 5-item displays, 210 msec for 7-item displays, 330 msec for 11-item displays). At these display times, controls were expected to show close to perfect levels of accuracy at all display sizes. After a delay of 100 msec, a mask (consisting of a random line pattern) was presented for 75 msec, thus terminating stimulus processing. The aim was to reduce the effects of visuo-motor coordination, decision processes and eye movements on performance, while still allowing enough time for visual search across the limited target set. The performance measure was accuracy.

Participants were informed that they could take a break at any time and were given a 3 min break at the end of each block regardless of whether any other breaks had been taken.

4.1.2 Results

Parallel search

A repeated measures Analysis of Variance (ANOVA) with target feature (orientation, size) and set size (5, 7, 11 items) as within-subject factors, and group (control, dyslexia) as the between-subject factor indicated no significant main effects nor any significant interactions between variables. Thus at the group level there are no differences in searching for a target which is distinguishable from distractor items by a single feature of orientation or size. Separate ANOVAs were carried out for each individual with dyslexia which showed RTs of all cases to be unaffected by increase in set size. Thus, performance was consistent with parallel, pre-attentive search previously reported for this type of task. Comparison of overall mean RT was made, between each ADys case and the control group, using the modified t-test (see Chapter 3). Only cases GM and TC showed slower RTs (927 and 922 msec, respectively) compared to the control group (mean RT = 666, s.e.m. = 42 msec: \( p < 0.01 \)).
Serial search

Separate repeated measure ANOVAs of RT and accuracy data were performed with set size (5, 7, 11 items) as the within-subject measure, and group (control, dyslexia) as the between-subject factor. For RT, a significant main effect of set size \((F(2, 36) = 46.9, p < 0.001)\) was observed. This indicated that RT increased as set size increased for both groups. A significant main effect of group was also found \((F(1, 18) = 6.7, p < 0.05)\), indicating slower RTs for the ADys group (1055 msec) compared to the control group (810 msec). A summary of results is presented in Figure 4.2.

Figure 4.2: Performance measures for serial search as a function of number of items presented (set size). A and B represent RT performance when sets were presented until a response was given. C and D represent accuracy performance when sets were presented for 30 msec per item. A and C provide results for group comparisons while B and D provide comparisons of individual dyslexia cases to the control group.
From Figure 4.2A it can be seen that RTs for the dyslexia group were generally longer than the control group across set size. Analyses of the individual data indicated a set size effect for all cases \( (p < 0.05) \) (see Figure 4.2B). Individual case to control group analyses using the modified \( t \)-test indicated that cases GM, TM and JM showed a significantly longer overall mean RT and significantly greater slope than the control group \( (p < 0.05) \). This may be indicative of a motor control deficit for these cases.

For accuracy, significant main effects for set size \( (F(2,36) = 13.8, \ p < 0.001) \), and group \( (F(1,18) = 13.3, \ p < 0.01) \) and a set size × group interaction \( (F(2,36) = 8.2, \ p < 0.01) \) were observed. Accuracy was generally poorer for the ADys group \( (78\%) \) compared to the control group \( (95\%) \). To investigate the 2-way interaction, separate RM-ANOVAs were conducted for each group. For the control group, no significant change in accuracy occurred as set size increased \( (F(2,22) = 0.5, \ p > 0.5) \), while the group with dyslexia demonstrated decreased accuracy as set size increased \( (F(2,14) = 17.0, \ p < 0.001) \) (see Figure 4.2C). Analyses of the individual data also indicated a significant set size effect for all cases, \( (p < 0.05) \) (see Figure 4.2D). Thus, for all cases, conjunction search becomes more difficult as the number of items in the display increases, indicating a possible deficit in top-down mechanisms of attention.

4.1.3 Discussion

The visual search results provide partial support for previous findings (Buchholz and McKone, 2004; Casco and Prunetti, 1996; Iles, Walsh, and Richardson, 2000; Vidyasagar, 1999) and provide evidence that individuals with dyslexia have deficits associated with visuospatial attention. Specifically, this may be a deficit in shifting and/or scaling the attentional focus. The results of this experiment also demonstrate that the response time measure of this task does not provide the best measure of performance difference between individuals with dyslexia and a control group: the accuracy measure is a better because it
removes the confound of motor response difficulties found in RT measures. It is unlikely that the set size effects observed in the accuracy version of the visual search paradigm were due to other factors, such as eye movements or motor response times as these were controlled for through short stimulus display times and forced-choice responses.

Given that the magnocellular pathway has been attributed a spotlight function in focusing spatial attention (Vidyasagar, 1998, 1999), and deficits of this pathway have been shown to exist in dyslexia (Badcock and Lovegrove, 1981; Breitmeyer, 1993; Cornelissen and Hansen, 1998; Demb, Boynton, and Heeger, 1998; Eden, VanMeter, Rumsey, Maisong, Woods, and Zeffiro, 1996a; Livingstone, Rosen, Drislane, and Galaburda, 1991; Lovegrove, Bowling, Badcock, and Blackwood, 1980; Lovegrove, Martin, and Slaghuis, 1986; Stein and Walsh, 1997), the results of this study support the hypothesis that the reading disability in dyslexia may be caused by an attentional deficit. This idea is also consistent with the results of a study by Steinman, Steinman, and Garzia (1998) that measured the spatiotemporal attentional response functions of both poor and normal readers using a Line Motion Illusion task.

According to Vidyasagar (1999, 2001), reading requires an unnatural use of visual search mechanisms. Normally, visual search is a random process which does not keep track of previously inspected locations (Horowitz and Wolfe, 1998). However, when reading, the attentional spotlight needs to be trained to move ‘sequentially and systematically’ over the words in a line. In this way, the letters could be attended to and integrated into words. Individuals who have a deficient magnocellular pathway may not be able to learn this skill effectively and therefore their reading capabilities will be poorer and slower to develop.

Visuospatial attention has several components and the results of visual search alone cannot determine the precise nature of the visuospatial deficit observed. For example, visual search requires the employment of attentional resources to process spatial information (the location of objects) as well as
object information (the specific features of an object). Thus, the visual search deficits observed in dyslexia may relate to one or both of these processes. In addition, this experiment did not examine processing in each visual field separately or processing at varying eccentricities. These aspects of attention will be examined in the chapters that follow.
Chapter 5

Attentional blink

One method of estimating the time spent attending to stimuli in a display is to examine the slope of the target-absent RT against display size in a visual search paradigm. The rate of such a visual search is usually reported at about 50 ms per item (Horowitz and Wolfe, 1998; Treisman, 1990; Treisman and Gelade, 1980; Pashler, 1987). However, while at face value this estimate may appear sound, there may be interpretive problems with the method. For example, this estimate relies on the search being strictly serial, however other models of visual search have been proposed with varying degrees and types of parallelism (Duncan and Humphreys, 1992; Grossberg, Mingolla, and Ross, 1994; Palmer, Ames, and Lindsey, 1993; Wolfe, 1994). As a consequence, if parallel processing were occurring for non-targets then dwell time estimates would not be accurate. Furthermore, as indicated in Chapter 4, RT measures of performance on visual search tasks, by individuals with dyslexia, do not account for possible confounding factors such as eye movement and motor response times.

In contrast to the simultaneous displays used in visual search tasks, other paradigms have been developed that examine the time course of attention during the sequential presentation of stimuli. These paradigms rely on Rapid
Serial Visual Presentation (RSVP) of stimuli, and vary according to the simplicity of the task. One variation requires participants to report one or two target items, distinguishable on some physical characteristic (such as digit), presented within a stream of stimuli (often alphanumeric characters). It has been generally found that control participants are severely impaired at detecting the second target, referred to as T2, when it is presented within 500 msec of a correctly identified first target, referred to as T1 (Duncan, Ward, and Shapiro, 1994b; Raymond, Shapiro, and Arnell, 1992; Ward, 1999). Raymond et al. (1992) termed this impairment an attentional blink (AB), an analogy to a suppression of visual processing that occurs during rapid saccadic eye movements (Volkman, Riggs, and Moore, 1980).

Several different models have been proposed to account for the AB, all of which emphasize that deficits in T2 processing are caused by the requirement to attend and process T1 (Chun, 1997; Isaak, Shapiro, and Martin, 1999; Olson, Chun, and Anderson, 2001; Potter, Staub, and O’Connor, 2002; Shapiro, Arnell, and Raymond, 1997). When items are presented rapidly, as in the RSVP, attentional resources which mediate selection and identification of a target are heavily taxed. Specifically, distractors interfere with target identification by masking the target representation (Chun and Potter, 1995; Seiffert and Di Lollo, 1997; Vogel and Luck, 2002) and by competing for identification and representation in short-term memory (Shapiro et al., 1994). Furthermore, it has been recently demonstrated that during the AB, a delay between detection and selection of targets occurs (Nieuwenstein, Chun, van der Lubbe, and Hooge, 2005). Thus, if T2 is presented before T1 has been processed and admitted into short-term memory (STM), it cannot be processed efficiently and is therefore vulnerable to passive decay and retroactive interference. Increasing the time between T1 and T2 presentation allows T1 to be more completely processed, thereby releasing attentional resources for T2 selection and processing.

To my knowledge, only three studies have previously examined AB in
dyslexia. For example, Hari, Valta, and Uutela (1999) examined a group of adults with dyslexia. In their RSVP task, distractors were black letters, T1 was a white letter and T2 was a black ‘X’. The participants were required to identify T1 and report whether T2 was also presented. The group with dyslexia showed a significantly longer AB with maximum performance at stimulus onset asynchrony (SOA) of approximately 700 msec, compared to the control group whose maximum performance occurred at approximately 540 msec. This was interpreted as indicating that the attentional capacity of the dyslexia group was occupied for a longer period than the control group. That is, they had a longer *attentional dwell time*.

Naming deficits for objects, colours, letters and sometimes digits have been reported in dyslexia research (e.g., Denckla and Rudel, 1976; Landerl, 2001; Miles and Gibbons, 2002; Wolf, Bally, and Morris, 1986). Thus the AB reported by Hari et al. (1999) may have in part been due to language-specific factors rather than an attentional problem per se. In an AB study of children with dyslexia, Visser, Boden, and Giaschi (2004) used non-linguistic stimuli. Targets were geometric shapes which were identified by pressing an appropriate matching button on a custom designed button box, alleviating the requirement for naming. The distractor items were patches of random dots. The group with dyslexia demonstrated longer AB than an age-matched control group with performance deficits remaining at 1400 msec. However, their performance was similar to the AB of a reading-matched group of younger children. In addition, Visser et al. (2004) made the observation that the AB found by Hari et al. (1999) in adults with dyslexia was shorter than the AB of their children with dyslexia. Based on the results of these two studies, they suggested that the longer AB observed in dyslexia arise from attentional difficulties which (at least in part) might stem from developmental delays. That is, the attentional system is slower to mature for some of the children with dyslexia, while for others it may not ever fully mature.

Performance of adolescents with dyslexia was examined by Lacroix, Con-
stantinescu, Cousineau, Almeida, Segalowitz, and von Grunau (2005) using an RSVP task in which distractors were white digits and targets were red digits. Contrary to the findings of Hari et al. (1999) and Visser et al. (2004), Lacroix et al. (2005) found the group with dyslexia showed shorter AB than the control group. They suggested that the shorter AB occurred because, unlike skilled readers, those with dyslexia are unable to automatically process the symbolic stimuli (digits) used in their study beyond initial encoding necessary for recall at the end of each trial. However, Lacroix et al. (2005) reported that the T1 accuracy of the dyslexia group was comparable to that of the control group. Thus it appeared the adolescents with dyslexia could allocate similar amounts of resources to maintain the targets in working memory.

Visser et al. (2004) also examined the effect of distractors on target identification. They suggested that examining the accuracy of identifying a single target amongst distractors would reveal if interference from preceding distractors causes the decrease in identification of the target. In their study, they observed similar performances by both the control and dyslexia group on such a task, thus concluding that AB is the consequence of having to identify the first target and is not due to distractor interference alone. It has been suggested that the time required for T1 to be consolidated into STM depends on factors such as confusability between T1 and subsequent distractors (Chun and Potter, 1995; Raymond, Shapiro, and Arnell, 1995). The implications of this to previous dyslexia studies is that the perceptual interference from distractors may have been the contributing factor to the longer AB seen in the dyslexia groups. Interestingly, Visser et al. (2004) found that an AB (longer in the dyslexia group) occurred even when distractors were perceptually dissimilar to the targets. This finding suggests that the AB observed in dyslexia is not due to perceptual interference, but rather to difficulty in allocating attentional resources necessary for target identification.
5.1 Experiment 2

In the present study, the effect of varying target characteristic (based on conceptual category) on AB was examined. In the first experimental condition, all items shared the same conceptual category (digits) with target selection based on the physical characteristic of colour (target = red; distractors = black). In the second experimental condition, the target was again red but differed in conceptual category to the distractor items (target = letter; distractors = black digits). If the individuals with dyslexia find it difficult to follow a stimulus flow and efficiently encode stimulus-specific information into memory, then they should show a longer AB than the control group. That is, it should be more difficult for them to report the second target when the first has been successfully identified. If, on the other hand, the difficulty they have is in automatically processing symbolic stimuli (digits or letters), beyond initial encoding necessary for recall, then they should show a shorter AB. Finally, if the AB shown by the individuals with dyslexia are due to the linguistic nature of the stimuli, then the AB should be similar in the two conditions since both require naming of stimuli. To determine whether the requirements of attending to two consecutive targets impaired identification of both targets, identification accuracy of T1 was also examined. To examine the role of distractors, an additional condition was included in which a single target was presented for identification amongst the RSVP stream.

5.1.1 Method

Participants

Five ADys cases from the experimental pool: GP, SM, SW, GM and TC participated in this experiment (cases TM, RM and JM were unavailable). The control group consisted of eleven adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.
Apparatus and stimuli

Stimuli were presented using Psycscope on an Apple computer running OS-9 with a 17-inch computer screen and a refresh rate of 85 Hz. The viewing distance was set to 50 cm using a chin rest. The stimuli were digits (1-9) or upper-case letters (Geneva font: A, D, G, J, L, P, T, U) subtending approximately $0.7^\circ \times 0.7^\circ$ of visual angle.

Procedure

Four conditions were run in separate sessions. In each condition, trials began with the appearance of a fixation cross (+) at the centre of the computer screen for 800 msec indicating where the stimulus items would appear. Participants were instructed to maintain their eye gaze on the location of the fixation cross. This was followed by a blank screen for 200 msec and an RSVP stream of 16 black digits presented on a light grey background (40 cd/m$^2$).

In the initial conditions, a single target, either a red digit or a letter, was embedded within the RSVP stream of black digits. In the experimental conditions, two non-identical targets, either two red digits or two red letters, were randomly embedded (see Figure 5.1 for the digit condition). Each stimulus was presented for 100 msec and was never presented twice in a row.

In the experimental conditions, the first target (T1) always appeared in position 3 to 7 within the stream, and was separated from the second target (T2) by 1 (SOA = 200 msec; Lag 1), 3 (SOA = 400 msec; Lag 3), 5 (SOA = 600 msec; Lag 5), or 7 (SOA = 800 msec; Lag 7) distractor(s). The initial conditions were identical to the experimental conditions except that T1 was omitted and replaced with a black digit.

At the completion of the trial, participants were presented with a question on the screen asking for the identification of each target, which they reported by pressing the corresponding key on the keyboard. For each experimental
condition, a block of 20 practice trials was followed by 5 experimental blocks of 80 trials. Within each experimental block, this corresponded to 20 trials for each of the four lags.

Figure 5.1: RSVP paradigm procedure for the experimental condition where targets (red digits) and distractors (black digits) belonged to the same conceptual category, digits. In the second experimental condition, the distractors remained the same but the targets were red letters, thus belonging to a different conceptual category.

To allow the number of distractors to be equated, the single target in the initial conditions appeared at the same location (notional lag) in the RSVP stream as T2 appeared in the experimental conditions. This allowed T2 performance to be estimated in the absence of T1 in the RSVP stream.
5.1.2 Results

Initial conditions

Mean accuracy of target identification at each notional lag, in each initial condition, was calculated for each participant. An omnibus repeated measures Analysis of Variance (RM-ANOVA) with Condition (digit, letter) and Notional Lag (1, 3, 5, 7) as the within-subject factors, and group (control, dyslexia) as a between-subject factor, was carried out on this data. A significant main effect of Lag ($F(3, 42) = 8.95, p < 0.001$) was found. No other significant main effects or interactions were found ($p > 0.3$).

Table 5.1: Accuracy of single target identification as a function of notional lag, presented for the two groups (control, ADys) and each adult dyslexia case.

<table>
<thead>
<tr>
<th>Notional Lag</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group (n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>94.36</td>
<td>94.55</td>
<td>96.55</td>
<td>97.45</td>
</tr>
<tr>
<td>s.d.</td>
<td>2.80</td>
<td>3.21</td>
<td>2.94</td>
<td>1.75</td>
</tr>
<tr>
<td>Dyslexia Group (n=5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average</td>
<td>91.00</td>
<td>92.60</td>
<td>94.20</td>
<td>94.60</td>
</tr>
<tr>
<td>s.d.</td>
<td>4.36</td>
<td>6.07</td>
<td>4.76</td>
<td>4.88</td>
</tr>
<tr>
<td>Dyslexia Individuals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td>92</td>
<td>96</td>
<td>98</td>
<td>96</td>
</tr>
<tr>
<td>SM</td>
<td>95</td>
<td>93</td>
<td>95</td>
<td>98</td>
</tr>
<tr>
<td>SW</td>
<td>90</td>
<td>96</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>GM</td>
<td>84</td>
<td>82</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>TC</td>
<td>94</td>
<td>96</td>
<td>97</td>
<td>97</td>
</tr>
</tbody>
</table>

Note that digits in **bold** indicate a significant difference when compared to the control group, $p < 0.01$.

As seen in Table 5.1, each ADys case showed some improvement with notional lag. Overall, these results demonstrate improved accuracy with increas-
ing notional lag for both the ADys cases and the control group. Mean accuracy of target identification was 95.7% for the control group and 93.1% for the dyslexia group. Also from Table 5.1, it appears that case GM does not reach the same accuracy performance as the control group at all notional lags. This was affirmed by a modified $t$-test (see Chapter 3), indicating case GM was significantly less accurate than the control group at each lag ($p < 0.01$). Thus, while case GM is able to identify a single target, it may be that the fast presentation rate causes greater difficulty than for the other cases and the control group.

These findings support those of Visser et al. (2004) and may reflect an increase in participant alertness in preparation for the target, made possible by the increase in time before its presentation (Posner, 1980). Importantly, these findings indicate that the participants in this study are able to identify a single object in an RSVP stream. This is also consistent with the previous results by Tallal (1980), Blackwell et al. (1983), and Klein et al. (1990). It has previously been suggested that performance deficits observed in the experimental condition are a consequence of identifying T1 rather than distractor interference alone (Visser et al., 2004). That is, the requirement to increase the allocation of attentional resources to identify T1 may also result in the distractors being partially processed, leading to interference and thus reduced ability to attend and identify both T1 and T2. Thus, the AB provides a measure of efficiency in attentional allocation (Raymond et al., 1992; Seiffert and Di Lollo, 1997).

**Experimental conditions**

Mean percentages of correct T1 identification in each experimental condition, as a function of the lag between T1 and T2, are illustrated for each experimental group in Figure 5.2. An omnibus RM-ANOVA with Experimental Condition (digit, letter) and Lag (1, 3, 5, 7) as the within-subjects factors and group (control, dyslexia) as a between-subjects factor was carried out. This analysis
revealed significant main effects of Experimental Condition ($F(1, 14) = 9.64$, $p < 0.01$), Lag ($F(3, 42) = 7.47$, $p < 0.001$) and Group ($F(1, 14) = 5.87$, $p < 0.05$). A significant Experimental Condition by Group interaction was also observed ($F(1, 14) = 12.39$, $p < 0.01$). These results indicate that overall T1 accuracy was (a) poorer in the digit condition (92.2%) than in the letter condition (94.3%), (b) gradually improved as lag increased for both groups, and (c) lower in the group with dyslexia (89.6%) than in the control group (96.8%). Follow-up paired sample t-tests revealed that the improved performance in the letter condition could be attributed to the dyslexia group who showed significant improvement ($t(4) = 2.91$, $p < 0.05$). Performance across the two experimental conditions did not differ significantly for the the control group ($t(10) = 0.46$, $p > 0.50$). This is not surprising given that overall performance in each condition was close to ceiling. From Figure 5.2 it can be seen that the dyslexia group showed greater variability than the control group.

![Figure 5.2: Mean T1 response accuracy for each group as a function of different intervals between T1 and T2; A. digit condition; B. letter condition](image)

Mean percentages of correct T1 identification in each experimental condition, as a function of the lag between T1 and T2, are illustrated for the control group and each ADys case in Figure 5.3.
Figure 5.3: Mean T1 response accuracy for the control group and each individual ADys case as a function of different intervals between T1 and T2; A. digit condition; B. letter condition

For each experimental condition, modified t-tests were carried out to compare the performance of each ADys case with that of the control group at each lag. In the digit condition, case SM met the accuracy level of the control group only after a 400 msec lag ($p > 0.05$). Case SW initially performed as well as the control group ($p > 0.05$), but appeared to have greater difficulty at longer lags ($p < 0.01$). This may be indicative of a deficit in the ability to maintain T1 in short-term memory with increasing distractor interference. The performance of all the other ADys cases was below that of the control group across lags ($p < 0.01$). In the letter condition, cases SM, SW and GP performed as well as the control group across all lags ($p > 0.05$). While both cases TC and GM showed improvement in the letter condition, only case TC reached the same level of performance as the control group (95% confidence interval) at 800 msec lag ($p > 0.05$). The performance of case GM appears to asymptote at around 75-80% accuracy in both experimental conditions.

Mean percentages of correct T2 identification in each experimental condition, as a function of the lag between T1 and T2, are illustrated for each experimental group in Figure 5.4. An omnibus RM-ANOVA with Experi-
mental Condition (digit, letter) and Lag (1, 3, 5, 7) as the within-subjects factors and group (control, dyslexia) as a between-subjects factor was carried out. This analysis revealed significant main effects of Experimental Condition ($F(1,14) = 58.07$, $p < 0.001$), Lag ($F(3,42) = 44.77$, $p < 0.001$) and Group ($F(1,14) = 14.97$, $p < 0.01$). A significant Experimental Condition by Lag interaction was also observed ($F(3,42) = 16.87$, $p < 0.001$).

These results indicate that overall T2 accuracy for both groups was (a) poorer in the digit condition (76.74%) than the letter condition (88.65%), (b) gradually improved as lag increased, consistent with the presence of an AB in both groups, and (c) lower in the group with dyslexia (75.25%) than in the control group (90.14%). Follow-up contrasts between each lag revealed that, for the digit condition, performance improved across all lag increases whereas, in the letter condition, performance reached asymptote at lag 5, that is, 600 msec ($p < 0.05$). Furthermore, a paired-sample $t$-test comparison of the two experimental conditions, for performance change between lag 3 and lag 1, revealed that the AB was significantly longer in the digit condition than the letter condition ($p < 0.001$).

Figure 5.4: Mean T2 response accuracy for each group as a function of different intervals between T1 and T2; A. digit condition; B. letter condition
From Figure 5.4 it appears that the AB difference between control and ADys groups was not the same across all experimental conditions. To test this, independent $t$-tests at each lag were carried out for each experimental condition. The results indicated that the ADys group reached the same level of performance as the control group at lag 7 in the digit condition, but at lag 5 in the letter condition ($p > 0.05$), equal variance not assumed). At the 90% performance level, the AB for the control group in the digit condition was approximately 400 msec, and in the letter condition approximately 250 msec; for the dyslexia group it was 800 msec and 600 msec respectively. Note that the difference between the two groups remained relatively the same across all experimental conditions (approximately 400 msec). Also from Figure 5.4 it can be seen that the dyslexia group showed greater variability in each experimental condition than the control group.

![Figure 5.5: Mean T2 response accuracy for the control group and each individual ADys case as a function of different intervals between T1 and T2; A. digit condition; B. letter condition](image)

Mean percentages of correct T2 identification in each experimental condition, as a function of the lag between T1 and T2, are illustrated for the control group and each ADys case in Figure 5.5. For each experimental condition,
modified t-tests were carried out to compare the performance of each ADys case with that of the control group. In the digit condition, the accuracy level of the control group was met by case SW at 400 msec, case SM at 600 msec, and cases GP and TC at 800 msec ($p < 0.01$). In the letter condition, performance was comparable to the control group for cases SM and GP across all lags, and for case SW at 400 msec ($p > 0.05$). Cases TC and GM showed poorer performance than the control group at all lags ($p < 0.01$). Paired sample t-tests indicated that the performance of all the ADys cases showed overall improvement in accuracy in the letter condition compared to the digit condition ($p < 0.05$).

### 5.1.3 Discussion

At the group level, the results of the present study are consistent with the Hari et al. (1999) adult study and the Visser et al. (2004) child study, indicating an overall difficulty by the dyslexia group to process rapidly presented visual material. However, comparisons between each individual dyslexia case and the control group indicated that not all dyslexia cases presented with this difficulty. Furthermore, the degree of difficulty appeared dependent on the type of material being presented. Thus, the findings of this study suggest that while the resources required to process and identify rapidly presented material may be compromised in dyslexia, this is not a necessary (nor perhaps sufficient) cause for dyslexia. More specifically, the results suggest that a long AB is *not* proximally related to reading and as such limits any theory which may rely on AB.

As expected, the control group in this study showed impaired ability to identify a second target item when it was presented within 500 msec of a first target item. This is consistent with the AB reported in studies using similar paradigms (e.g., Duncan et al., 1994a; Raymond et al., 1992). The dyslexia group showed a longer AB, between 600 msec and 800 msec, in agreement with
that previously reported in adults with dyslexia (Hari et al., 1999). The difference in AB between the two groups across experimental condition remained relatively constant (approximately 400 msec), since both groups demonstrated improved performance when target selection was based on conceptual category rather than on the physical characteristic of colour. Accordingly, it is unlikely that linguistic processing deficits were responsible for the longer AB shown by the dyslexia group because no improvement would be expected given that both experimental conditions required items to be named. Distractor interference alone and decreased vigilance are also unlikely factors because the dyslexia group demonstrated good performance in identifying a single target amongst distractors. The deficit appears to be a consequence of the necessity to identify two targets from amongst distractors, presented in rapid succession. The additional finding of deficits in T1 identification for the dyslexia group suggest that the two targets are in competition for the resources necessary for identification. In contrast to the findings of Lacroix et al. (2005), and despite similar methodologies, the results of the present study indicate that the dyslexia group automatically process the stimuli beyond initial encoding necessary for recall at the end of each trial. Specifically, in the experimental condition where the target was a red digit, the individuals with dyslexia showed longer AB than the control group, not shorter as reported in the study by Lacroix et al. (2005). Thus, competition for attentional resources was occurring, and there was an associated difficulty for these individuals. The sample of adolescents tested by Lacroix et al. (2005) demonstrated more variability in the reading difficulties they exhibited, compared to the adults in the present study. Specifically, two subgroups showed comprehension difficulties in addition to word identification and/or word attack. Given the relatively small sample used, this may have led to the discrepancy between the two studies, and the findings of previous researchers (Hari, Valta, and Uutela, 1999; Visser, Boden, and Giaschi, 2004).

It has been suggested that differences on this measure of AB might stem from developmental delays (Visser et al., 2004). A comparison of AB length for
the dyslexia groups in Visser et al. (2004) (>1400 msec), Hari et al. (1999) (approximately 700 msec) and the present study (approximately 600 - 800 msec) supports this hypothesis. In addition, the current study shows that at the individual level, AB for the ADys cases is quite variable, with some showing performance close to that of the control group. This may indicate that they have at least partially overcome the attentional deficits (through maturation or development of strategies), and thus ameliorated the severity of the AB. Other performances, such as reading, may also benefit from the maturation and/or strategy development resulting in the compensated adult with dyslexia. However, the individual case findings suggest that there is no direct relationship between performance on the AB task and reading ability. Specifically, the performance of case SW was comparable to the control group, whereas case GM showed the most severe AB, yet both these cases showed severe reading difficulties (see Table 1). Thus, while present, difficulties in processing rapid stimuli does not appear directly related to the reading difficulties shown by the ADys cases in this study.

Of consideration, is the possibility that the poor performance of case GM may be due to this participant being the oldest. However, correlational analysis for the experimental conditions, of age against performance at each lag for each group were not significant ($p > 0.3$). Although not conclusive, given the small sample sizes, this suggests that performance was not dependent on age. Furthermore, case TC was the second youngest in the dyslexia sample and showed the second worst performance. However, even if age were a component, one would still expect some improvement in performance as attentional dwell time increases. Case GM did not show significant improvement in performance across lags. In research previously reported (Buchholz and Aimola Davies, 2006), cases GM and TC demonstrated difficulty on a task containing attentional distraction (auditory domain) and a task of auditory memory. It may be that these difficulties are also present within the visual domain and are responsible for the particularly poor performance on the attentional blink task.
in this study.

The results also indicate that stimulus characteristics play an important role in determining the size of the AB. A larger AB was found in the digit-only condition where all items were digits, compared to the letter-as-target condition where the targets were letters and the distractor items were digits. According to the two stage model of AB (Chun and Potter, 1995), the reduced AB occurs because letters are more conceptually dissimilar from the other items and therefore it is possible for participants to relax the target detection criteria. That is, fewer target-relevant features require detection in Stage 1 before T1 can move to Stage 2. T1 can exit Stage 2 sooner and is therefore more likely to be completely processed by the time T2 appears, allowing T2 to enter Stage 2, thus reducing the AB. In contrast, the interference model (Shapiro et al., 1994) of AB explains the effects of target-distractor dissimilarity differently. According to this model, increasing the dissimilarity between targets and distractors reduces competition of target masks (that is, the first distractor appearing following the target) and noncritical distractors (that is all other distractors) for the processing resources engaged by T1 and T2. Instead, when all the stimuli are digits, the target masks and noncritical distractors share the same conceptual category and many of the perceptual features with the target. Therefore they compete for many of the same processing resources. When the targets are letters, the masks and distractors compete less effectively because they do not belong to the same conceptual category. Thus the AB is reduced. Despite the differences in explanation, both models appear to agree that the degree of conceptual similarity between the targets and other items alters the level of attentional resources required to select and process the targets. These models also predict better T1 accuracy in the letter-as-target condition. However, while no significant effect of experimental condition was observed for T1 accuracy of the control group (in fact they performed near ceiling), the ADys cases showed significant improvement in the letter-as-target condition. Thus, it appears that the attentional system is less taxed in the letter-as-target condi-
tion than the digit-only condition, allowing better performances to be observed in the ADys cases. If linguistic difficulties were key to the difficulties shown by the individuals with dyslexia, one would expect changing the conceptual category of the target items being named relative to the distractor items (as in the letter-as-target condition) to either have no effect on performance or to worsen it. One would not expect improvement of performance in the letter-as-target condition relative to the digit-only condition (where all named items shared the same conceptual category).

Another interesting finding of this study was the improvement in T1 identification with increasing lag for both the control group and the individuals with dyslexia. This suggests that competition occurs between T1 and T2. It has recently been demonstrated that a delay between detection and selection of targets occurs during the AB (Nieuwenstein et al., 2005). At short lags when attention is flexible (see Potter, Staub, and O’Connor, 2002), a delay of T1 selection may allow involuntary shifts of attention to T2 resulting in competition with T1 for processing. An alternative explanation is that at short lags the delay between detection and selection of targets results in T1 occupying the visual short term memory store when T2 is presented (Shapiro et al., 1994). This in turn leads to competition for attentional resources, and identification accuracy of both targets is reduced. Again, while these explanations differ, both concur that competition for attentional resources is greater between the two targets at short lags.

**Conclusions**

This study showed that variations in target processing requirements, as determined by conceptual similarity to distractor items, could alter the performance on an AB task. The findings also demonstrate that the long AB observed in dyslexia do not result from difficulties in processing linguistic stimuli, that is naming of stimuli. These findings have important implications in the study
of attentional processes in dyslexia since they indicate that deficits may be ameliorated or at least reduced under certain experimental conditions. The case-by-case analyses showed that although all individuals with dyslexia have a reduced attentional capacity, there did not appear to be a direct relationship between the magnitude of the AB and the degree of reading difficulty. This lack of a proximal relationship between AB and reading places strong limitations on any theory of dyslexia that relies on AB.
Chapter 6

Space- and object-based attention

There are two major views of how covert visual attention selects information for further processing. The space-based view holds that attention is directed to a specific area in space, and is unaffected by the presence of objects at that location. Evidence for spatial selection comes mostly from cueing studies (e.g., Posner, 1980). In these studies, spatial attention is varied by precueing the location of a target stimulus. Cueing may be valid, where the cue indicates the spatial location of the subsequent target, or invalid, where the cue indicates a different location. Typically, responses are faster and more accurate when stimuli are presented at cued relative to uncued locations (the valid cue effect). This finding has been observed with different types of stimuli, at different locations in the visual field, in different tasks (detection, discrimination, identification) and when the target appears in both empty and cluttered visual fields (e.g., Downing, 1988; Muller and Findlay, 1987). In contrast, the object-based view says that information about particular objects is selected independently of the objects spatial location. One of the earlier demonstrations of object-based attention was reported by Duncan (1984). In this study,
Chapter 6: Space- and object-based attention

Subjects viewed a display consisting of a rectangle with a tilted line drawn through the middle. The line could be tilted left or right, and was either dotted or dashed. The rectangle could be tall or short, and had a small gap either on the right or left side. After the display was briefly presented, subjects were required to report two attributes, either belonging to the same object or to different objects. Responses were more accurate when both attributes belonged to the same object. Duncan suggested that this was evidence that observers attend objects as a whole. When attention needed to shift from one object to another, costs in accuracy were incurred. A variety of different experimental studies have provided further evidence for object-based selection such as those examining cued detection and cued discrimination (Abrams and Law, 2000; Brawn and Snowden, 2000; Lamy and Tsal, 2000), response-competition (Kramer, Weber, and Watson, 1997) and dissociations in neurological patients (Egly, Driver, and Rafal, 1994a) (for a review see Scholl, 2001). The main findings of these studies are that: (a) attention can be split among multiple moving objects which do not occupy a connected region in space, (b) object-based factors can modulate cueing effects, (c) grouping between targets and distractors can influence the magnitude of response-competition, and override the effects of the distance between stimuli under certain conditions.

Some investigators have suggested that both systems could operate independently, with the component being employed being determined by the type of task and level of visual representation demanded by the task (Vecera and Farah, 1994). For example, simple detection tasks may access a spatial representation, while shape discrimination tasks require object-based representations. Egly, Driver, and Rafal (1994a) developed a variation of Posner’s (Posner, Snyder, and Davidson, 1980) precueing methodology, which allowed both space-based and object-based components of attention to be measured in a single task. Two adjacent (vertical or horizontal) rectangles appeared in the visual display. After a short time, the edge of one end of one rectangle was brightened briefly, cueing the subject to attend to that location while
maintaining central fixation. Participants were then required to detect a dark square within the cued rectangle or within the uncued rectangle. As is usual for cueing experiments, responses to validly-cued targets were faster than to invalidly-cued targets, suggesting a space-based effect. This was the first cueing task to also allow object-based effects to be demonstrated, with the finding of faster responses when attention was drawn to an invalid location within a rectangle relative to an equidistant location in another rectangle. These findings have been replicated and extended upon (Abrams and Law, 2000; Moore, Yantis, and Vaughan, 1998).

Another suggestion has been that the two components act in an interactive way. For example, some experimental effects (such as inhibition of return) can be shown in either spatial- or object-based frames of reference (Behrmann and Tipper, 1999). A recent study by Lamy and Egeth (2002) has demonstrated that in order to observe object-based effects, the task requires shifts of attention (spatial cueing, same versus different judgment with asynchronous target onsets). When attention remains broadly distributed (same versus different judgment with simultaneous targets) or when tightly focused (response competition paradigm) no object-based effects are observed. This finding has been supported by Goldsmith and Yeari (2003), who showed that for both endogenous and exogenous orienting, object-based effects were observed only when the task was such as to allow shifts of attention. Again, under conditions of focused attention, object-based effects were not seen. Finally, a recent study by Soto and Blanco (2004) suggest that object- and space-based attention interact, with attention to location occurring before object-based attention.

6.1 Experiment 3

If we regard words as objects, and letters as features at locations within objects, then reading requires both components of selective attention. It is proposed that if either, or both, components are not functioning correctly, one
might expect reading difficulties. In the present study, the attentional abilities of adults with dyslexia were examined using the precueing methodology of Egly, Rafal, Driver, and Starrveveld (1994b). The aim was to investigate visual field differences in the group of individuals with dyslexia, and to determine if these differences were related specifically to particular space-based or object-based components of visual attention.

6.1.1 Method

Participants

Eight adults with dyslexia (ADys) participated in this experiment. The control group consisted of eight adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.

Materials and procedure

The stimuli were presented using PsyScript software on an Apple Macintosh computer with a 17-inch monitor and a refresh rate of 85 Hz. Objects in the fixation display were light grey and were drawn on a white background (see Figure 6.1. Each trial began with four rectangular objects (two in each visual field) presented on the screen in either a horizontal or vertical orientation. Each object subtended $4.5^\circ \times 1^\circ$ of visual angle. The distance between the two objects in a visual field was $4.5^\circ$, and the closest edge of any object was $2.5^\circ$ from the central fixation stimulus (a black plus sign, +). The fixation stimuli remained on screen throughout the experiment. After 1000 msec, a cueing display (a black U shape) was superimposed on the end of one of the objects in the fixation display for 100 msec. The target event appeared after a 200 msec delay.

In any given block of trials, the target (a black rectangle about $1^\circ \times 1^\circ$) appeared at the cued location on 60% of trials (valid cue) and at an uncued location on 20% of trials (invalid cue). On 10% of trials a target was presented
without a preceding cue (no cue) and in a further 10% of trials a cue was presented without a target (catch trials). On the invalid-cue trials, the target appeared equally often either at the opposite end of the cued object (within-object shift of attention) or in the adjacent object within the same hemifield (between-object shift of attention). Both types of shifts of attention were of equal distance, and the target never appeared at a position diagonal to the
cued location. The target remained on the screen for a maximum of 1200 msec. During this period, a key press ended the trial. Stimuli were presented in 6 blocks of 160 trials. All conditions were randomly intermixed in each block, with 50% of trials for each condition occurring in each visual field. Subjects were seated comfortably with their head supported on a chin rest which held their eyes level with the fixation cross at a distance of 70 cm from the monitor. They were instructed to maintain fixation throughout each trial. The task was to press the 0 key as soon as the target appeared. Subjects were encouraged to pause between blocks for not more than 2-3 minutes. Individual testing lasted approximately 45 minutes, and began with twenty randomised practice trials.

6.1.2 Results

Response times (RT) shorter than 100 msec were discarded as anticipations. The frequency of these errors was low in both the dyslexia and control group (0.62% vs 0.73%, respectively). For each participant, mean RT was calculated for each of the within-subject conditions. To increase power of the analyses, data for upper and lower locations were combined for each location in each visual field. Several repeated measures Analysis of Variance (ANOVA) were calculated in which the between-subject factor was always group (controls, individuals with dyslexia).

Cue type

Response times were entered into a three-way ANOVA, in which the within-subject factors were cue type (no cue, valid cue, invalid cue) and visual field of presentation (LVF, RVF). There was a significant main effect of group ($F(1,14) = 5.72, p < 0.05$), demonstrating slower RTs for the group with dyslexia (425 msec) compared with the control group (359 msec). There was also a significant main effect of cue type ($F(2,28) = 199.84, p < 0.001$), demonstrating faster mean RTs for valid-cue trials (323 msec) compared with
invalid-cue trials (354 msec) and no-cue trials (499 msec). There were no other significant findings for this analysis.

**Valid-cue condition**

Response times were entered into a four-way ANOVA, in which the within-subject factors were orientation of rectangles (vertical, horizontal), visual field (left, right) and position of cue presentation within the visual field (left, right). There was a significant main effect of group \(F(1, 14) = 7.21, \ p < 0.05\), demonstrating slower mean RTs for the group with dyslexia (353 msec) compared with the control group (289 msec). The only other significant finding was that of a two-way interaction between visual field and position of presentation \(F(1, 14) = 14.95, \ p < 0.01\), demonstrating faster RTs associated with stimuli presented close to fixation (right side of the LVF = 319 msec; left side of the RVF = 317 msec) compared with those presented more peripherally (left side of the LVF = 326 msec; right side of the RVF = 321 msec).

**Invalid-cue condition**

The cost of shifting attention was calculated by subtracting valid cue means from invalid-cue means (cue position being the same) for each condition. These were entered into a five-way ANOVA, where the within-subject factors were orientation of rectangle (horizontal, vertical), type of attentional shift (within, between), visual field (left, right) and position of cue presentation (left, right). There was a significant main effect of shift type \(F(1, 14) = 35.75, \ p < 0.001\), demonstrating lower costs for within-object shifts (19 msec) compared with between-object shifts (39 msec). The visual field by position of cue presentation interaction was also significant \(F(1, 14) = 30.79, \ p < 0.001\), demonstrating lower costs for attentional shifts toward fixation (shift left to right in the LVF = 19 msec; shift right to left in the RVF = 17 msec) compared with those away from fixation (shift right to left in the LVF = 42 msec; shift left to
right in the RVF = 38 msec). A significant five-way interaction was also found ($F(1,14) = 59.51, p < 0.001$) (see Figure 6.2).

![Figure 6.2: Mean RT costs as a function of rectangle orientation, invalid-cue condition and visual field.](image)

*Represents significant differences between the control group and the group with dyslexia. ** Represents significant differences between the two groups for shifts away from fixation.

Planned comparisons revealed, first, that the group with dyslexia (compared to the control group) showed greater attentional costs for between-object shifts in the LVF ($t(14) = 1.99, p < 0.05$). Second, this group showed comparatively greater costs for shifts away from fixation ($p < 0.01$, see Figure 6.2).
Also, there was a trend for this group with dyslexia to have comparatively lower costs than the control group for shifts toward fixation, however, only the between-object shifts (in the vertically-oriented rectangles) toward fixation in the RVF reached significance ($t(14) = 3.06$, $p < 0.01$, see Figure 6.2). Finally, the group with dyslexia showed higher costs compared to the control group for up and down shifts of attention in the periphery, that is, shifts on the right of the RVF and left of the LVF ($p < 0.01$, see Figure 6.2).

6.1.3 Discussion

The results of this study have shown that the ability of adults with dyslexia to covertly orient attention following a precue is generally intact in both hemispheres, in that these individuals show the same overall pattern of responses as controls. That is, they are faster to detect validly-cued targets compared with invalidly-cued targets or targets without a cue. Adults with dyslexia also demonstrated a normal overall pattern of responses for object-based and space-based components of orienting, in that they were faster at responding to within-object shifts of attention compared to between-object shifts of attention. However, there were some consistent differences in the responses made by individuals with dyslexia. First, the findings clearly indicate that there were visual field differences for the between-object component of covert orienting of attention since the adults with dyslexia demonstrated slower responses to between-object shifts of attention in the left visual field. Second, and consistent with previous findings with children (Brannan and Williams, 1987; Facoetti and Molteni, 2001), the adults with dyslexia in the present study demonstrated difficulties in engaging stimuli at the periphery. This was clearly demonstrated in the finding that the adults with dyslexia were slower to detect validly-cued targets, regardless of position in the visual field. In addition, these individuals also demonstrated significant difficulties with movement away from the fovea in both visual fields, while a trend for faster orienting toward the
fovea was apparent. Shifting attention in an up and down direction at the periphery was also slowed. These findings may indicate that individuals with dyslexia have difficulties with maintaining and shifting attention which occurs in addition to their difficulties demonstrated with engaging attention in the periphery. This is an area requiring further investigation.

Fluent reading requires learned left-to-right and right-to left shifts of covert attention away from a central fixation point. These shifts need to be maintained long enough for some processing of the written word to occur before overt recognition takes place. Also, since written information is presented to both visual fields transfer between hemispheres is necessary. Clearly the results of this study have shown differences in the pattern of covert orienting of attention between adults with dyslexia and those without, which could have negative effects on the requirements of reading listed above. Future research is needed to investigate the relative importance of each apparent attentional difficulty to reading ability.
Chapter 7

Examining object based attention

The methodology developed by Egly, Driver, and Rafal (1994a) to examine both space- and object-based attention, as was used in Experiment 3, has come under question. Specifically, Vecera (1994) found that the object-based attention effects reported by Egly, Driver, and Rafal (1994a); Egly, Rafal, Driver, and Starrveveld (1994b) are sensitive to spatial manipulations, and as such may not provide a pure measure of object-based attention. Thus, any difference observed between the control and dyslexia groups in Experiment 4 of this thesis, may merely reflect differences in space-based attentional orienting rather than object-based attentional orienting. Furthermore, Valsangkar-Smyth, Donovan, Sinnett, Dawson, and Kingstone (2004) recently tested the conclusion by Egly et al. (1994a,b) that object-based attention is a specialized function of the left-hemisphere. They used a methodology developed by Duncan (1984), which examines the accuracy of attending to two objects as opposed to one, that is, they presumably examined object-based attention alone. Contrary to Egly et al. (1994a,b), their findings favoured a right-hemisphere bias for object-based attention.
7.1 Experiment 4

In this experiment, object-based attention was examined in isolation, using a methodology similar to Valsangkar-Smyth et al. (2004, Experiment 3), to clarify the findings presented in Experiment 4 of this thesis.

7.1.1 Method

Participants

Five ADys cases from the experimental pool: GP, SM, SW, GM and TC participated in this experiment (cases TM, RM and JM were unavailable). The control group consisted of eleven adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.

Procedure

Stimuli were presented using Psyscope on an Apple computer running OS-9 with a 17-inch computer screen and a refresh rate of 85 Hz. The viewing distance was set to 50 cm using a chin rest. The methodology was similar to that used by Valsangkar-Smyth et al. (2004, Experiment 3). The display sequence is illustrated in Figure 7.1. A fixation preview was displayed for 500 msec. Overlapping target items—a box and a line—subtending $5.5^\circ \times 3.0^\circ$ were then presented randomly, either to the left or right of centre by $9^\circ$ (from fixation to middle of overlap). Each target item contained two attributes that varied randomly from trial-to-trial. For the box, the gap could appear at the top or bottom, and the concave sides were either curved or pointed. For the line, the slope could be from top left to bottom right or vice versa and was either solid or dashed. Display duration was 120 msec. A target mask, composed of all possible display items and jittered by $0.25^\circ$, was presented for 120 msec at the location of the target items. A probe display was presented in the same
Figure 7.1: Example object representation procedure. The task was to indicate, with an untimed response, which of the probes matched the target attribute. In the above illustration, the left probe has the top gap as does the target.

visual field as the target items and mask. This probe display consisted of two items positioned side by side that differed only on one attribute that was to be judged. For example, when the sides were to be judged, two rectangles were presented, the concave sides being curved on one rectangle and pointed on the other rectangle. When the probe display was presented on the left, the participant made an untimed response with their left hand using “z” or “x” to indicate whether the relevant attribute appeared in the left or the right probe respectively. When the display probe was on the right, the right hand was used to press “.” or “/”. In different blocks of trials, the participant was required to attend to the relevant attributes of the box or line (one object) or both the box and line (two objects). The order of these conditions was counterbalanced across participants. Each condition was composed of 160 trials divided equally between two blocks. Forty-two practice trials preceded testing in each condition.
7.1.2 Results

Performance for one- and two-object displays are presented for each group in Figure 7.2. A repeated measures Analysis of Variance (RM-ANOVA) was carried out, with object display (one or two) and visual field (left or right) as within-subject factors, and Group (control or dyslexia) as the between-subject factor. A main effect of object display \((F(1, 13) = 122.3, p < 0.001)\) was significant, indicating that response accuracy improved for both groups when selection was for one object. A main effect of group \((F(1, 13) = 16.2, p < 0.001)\) was also significant, indicating that overall performance was poorer for the dyslexia group (52%) compared to the control group (64%). No other effects or interactions were significant.

![Figure 7.2: Mean response accuracy for each group, as a function of target visual field and number of objects to be selected.](image)
Performance for one- and two-object displays are presented for the control group and each individual ADys case in Figure 7.3. Compared to the control group in the one object condition, case SM showed significantly poorer performance in the RVF, while all other ADys cases showed poorer performance in both visual fields ($p < 0.01$). Thus it appears that the dyslexia group generally found this task more difficult than the control group.

Compared to the control group in the two object condition, cases SM and TC showed significantly poorer performance in the RVF, and case GP showed poorer performance in both visual fields ($p < 0.01$). All other ADys cases showed no difference to the control group in performance in both visual fields ($p > 0.01$).

Figure 7.3: Mean response accuracy for the control group and each ADys case, as a function of target visual field and number of objects to be selected.
7.1.3 Discussion

Consistent with the findings of Valsangkar-Smyth et al. (2004), it was found that the accuracy performance was better when one object was presented. Unlike the previous research by Valsangkar-Smyth et al. (2004) and Egly et al. (1994a,b), no visual field advantage was observed when two objects were presented. That is, neither a left-hemisphere (RVF) bias (Valsangkar-Smyth et al., 2004), nor a right-hemisphere (LVF) bias (Egly et al., 1994a,b), was observed for the control group. Thus, the results of this experiment have not supported an hypothesis for cortical lateralization of object-based attention.

In comparison to the participants studied by Valsangkar-Smyth et al. (2004), the control group in this study showed poorer performance in the two-object condition (47% versus 66%). One possible explanation for this difference is age of the samples used in the two studies. In this experiment, the age of the control group participants was variable ($M = 35.9, s.d. = 9.67$ years). To examine the relationship between age and performance in the two conditions, a correlational analysis was performed. No significant relationship was found with the one-object condition, however a significant relationship was evident for the two-object condition ($r = 7.61, p < 0.05$, two-tailed). This indicated that performance on the two-object task improved as the age of the participant increased. This effect of age may confound the results for the dyslexia individuals, as the three cases who showed the poorest performance on the two-object task (cases SM, TC and GP) were also the youngest in the dyslexia group. Unfortunately, Valsangkar-Smyth et al. (2004) did not report the ages of participants although all were undergraduate students. However, it may be false to assume that undergraduate equates to under twenty five years of life.

Another possibility for the difference between the two studies may be that the participant pool used by Valsangkar-Smyth et al. (2004) were more practiced in carrying out psychophysical testing; resulting in better performance than the more inexperienced participants in this experiment. With increasing
task difficulty, the participants in this experiment may have favoured one of the objects to attend to for most of the trials at the expense of the other object, in the two-object task. This might explain why the accuracy performances were close to 50%. Thus, the reduced performance accuracy in the two-object condition may not reflect object-based attention *per se* but rather task difficulty. The dyslexia participants may have also adopted this strategy, resulting in similar performance levels as the control group. However, the performances of cases SM, TC and GP may reflect a difficulty in maintaining this strategy. Perhaps due to distraction from the multiple visual elements.

With respect to the one-object task, all ADys cases showed poorer performance than the control group, across both visual fields. This finding is consistent with previous research indicating a difficulty in processing rapidly presented visual stimuli (Hari, Valta, and Uutela, 1999; Visser, Boden, and Giaschi, 2004).

**Conclusion**

It does not appear that the methodology used in this experiment provides consistent results across studies, which may be due to several possible confounding variables. In terms of dyslexia research, the results of this study demonstrate a difficulty in processing rapidly presented visual stimuli.
Previously reported attentional difficulties in dyslexia have all related to a space-based component of attention, that is, to attention selecting a particular spatial region in the visual field from which information will be processed (Cave and Bichot, 1999). Metaphorically, this space-based attention has been referred to as a “spotlight” (Posner, 1980), a “zoom lens” (Eriksen and Yeh, 1985), or a “gradient” (Downing and Pinker, 1985). Increasingly, evidence is supporting the presence of an object-based component of selective attention that selects whole objects, or perceptual groups, that have been organized preattentively (for review see Scholl, 2001). Once selected, uniform processing of all the features and attributes of the visual object occurs, regardless of task relevance (Kahneman and Henik, 1981). When reading, both space- and object-based components of selective attention may be required.

To select the appropriate location of a word in a sentence (or an individual letter in a word), it would be expected that the space-based component of attention would be necessary, while the object-based component would be necessary for identifying the features of the word, thus allowing for word iden-
tification. In Experiment 4, space- and object-based attention in adults with dyslexia (ADys) was examined. Group analyses were conducted and differences were found in that ADys demonstrated greater difficulty both in shifting attention away from fixation (a specific spatial deficit) and in shifting attention between objects presented in the left visual field. Another non-linguistic factor that has been linked to reading ability is memory.

The most accepted model of short-term memory is that it operates as working memory with multiple components (Baddeley and Logie, 1999). A controlling attentional system (the central executive component) supervises and coordinates two subsidiary systems: the phonological loop and the visuospatial sketchpad, which respectively deal with information presented verbally or non-verbally. A number of experimental studies have supported the proposal that the phonological loop is composed of two subcomponents: a phonological store, where information is held for a limited period and a phonological rehearsal system, which refreshes the phonological store contents thereby lengthening memory trace duration (e.g., Baddeley and Logie, 1999; Salame and Baddeley, 1987). Hitch and colleagues (Hitch, Halliday, Dodd, and Littler, 1989; Hitch, Halliday, Schaafstal, and Schraagen, 1988) have demonstrated that visually presented information is often remembered by using a phonological strategy. That is, by converting the visual information into a phonological form (creating an internal monologue). Thus it appears that, with respect to reading, the phonological loop component of memory would be essential to learning to read. For example, storage and rehearsal would be necessary when first learning to read to allow the transfer of new letter-sound relationships to long-term memory for later retrieval. Also during the reading process, two or more phonemes must be integrated to produce a word (and several words to produce a sentence) that would also rely on storage and rehearsal. A great deal of research has been carried out to determine the relationship between short-term memory and literacy. Despite this, the extent to which successful literacy relies on short-term memory has yet to be established (for review see Pickering, 2004).
Longitudinal studies have found that memory performance before or at school entrance predicts later reading performance (e.g., Jorm, Share, MacLean, and Matthews, 1984). In addition, literacy difficulties have been linked with verbal working memory performance in children with developmental dyslexia (e.g., De Jong, 1998; Gathercole and Baddeley, 1993; Shankweiler, Crain, Brady, and Macaruso, 1992). However, Hulme and Roodenrys (1995) have argued that the memory problems shown by poor readers reflect phonological deficits rather than being predictive of reading disability. In contrast, Hansen and Bowey (1994) found that while a lot of common variance was shared by phonological awareness and verbal short-term memory, different reading-related skills appeared to be tapped by each process. Other research has also indicated that while memory functions and phonological awareness appear related, working memory does account for unique variance in reading performance (e.g., Cormier and Dea, 1997). Recently, Tijms (2004) reported on results suggesting that phonological deficits and verbal memory impairments in dyslexia stem from the same underlying phonological encoding deficit. Furthermore, this deficit was found to be a negative predictor of both reading and spelling in children with dyslexia.

8.1 Experiment 5

The aim of this study is to examine the relationship between deficits in visual attentional processes, auditory working memory ability and phonological ability (specifically phonological awareness). Individual performance of adult cases with dyslexia were examined and compared to a control sample, all of whom had achieved, or were currently enrolled in, tertiary education. To provide a comprehensive profile for each individual, a battery of neuropsychological tests was administered in addition to space- and object-based measures of covert attention. Neuropsychological testing included performance measures for literacy and phonological ability, overt visual attentional processing
(specifically on a visual search task where eye movements are permitted) and auditory working memory. The main questions addressed were: Do significant relationships exist between any of the measures of covert visual attention, overt visual attention, auditory working memory and phonological ability? What are the relative contributions of each measure to observed phonological deficits? Based on previous research we expect to find relationships between covert visual attention, overt visual attention and phonological ability, as well as between auditory working memory and phonological ability.

8.1.1 Method

Participants

Eight adults with dyslexia (ADys) participated in this experiment. The control group consisted of eight adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.

Psychometric measures: literacy and phonology

Level of literacy attainment was examined using the reading and spelling subtests of the Wide Range Achievement Test (WRAT-3: Wilkinson, 1993). Phonological Awareness (PA) was examined using the Phonemic Segmentation subtest of the DAST (Fawcett and Nicolson, 1998). Phonemic segmentation (manipulation) is considered a direct measure of phonological awareness (Adams, 1990). It tests the ability to break a word into its constituent sounds and manipulate those sounds (e.g., “say stake without the k”). The DAST includes a series of spoonerisms, a more complex test of this skill. It requires participants to exchange the beginning sound of two words presented orally (e.g., “John Lennon” becomes “Lon Jennon”).
**Psychometric measures: overt visual attention and auditory working memory**

Overt visual attentional abilities (where eye movements were permitted) and auditory working memory were assessed using two subtests (Map Search and Elevator Counting with Distraction) from the Test of Everyday Attention (TEA; Robertson, Ward, Ridgeway, and Nimmo-Smith, 1994). Map Search requires the participant to search a roadmap to find as many instances as possible of a pre-determined target (e.g., petrol station icon) among distractor items (e.g., repair shop icons and restaurant icons) in two minutes. Elevator Counting with Distraction requires the participant to listen for and count a particular tone that they are asked to think of as a floor travelled in an elevator, while ignoring other tones.

**Experimental measure: covert attention**

Covert attention was assessed using the Egly et al. (1994b) precueing paradigm, as presented for Experiment 3.

**8.1.2 Results**

The modified $t$-test (Crawford and Garthwaite, 2002) and the Revised Standardized Difference Test (RSDT Crawford and Garthwaite, 2005) were used to compare individual case scores with control group means for all measures (see Chapter 3. A summary of measures is presented in Table 8.1.2.

**Psychometric measures**

Analysis of data from the standardised literacy tests revealed that, compared to the control group, there was impaired performance for all Adys cases (except GP, SM and RM) on the reading test and all ADys cases (except SM and RM)
Table 8.1: Scores for control group (n=8) and each individual dyslexia case on tests of literacy, phonological awareness, overt attention, auditory memory and covert attention.

<table>
<thead>
<tr>
<th></th>
<th>Control mean (s.d.)</th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRAT: R&lt;sup&gt;a&lt;/sup&gt;</td>
<td>109.50 (5.10)</td>
<td>94</td>
<td>105</td>
<td>76</td>
<td>81</td>
<td>90</td>
<td>79</td>
<td>103</td>
<td>86</td>
</tr>
<tr>
<td>WRAT: S&lt;sup&gt;b&lt;/sup&gt;</td>
<td>114.00 (5.70)</td>
<td>87</td>
<td>100</td>
<td>73</td>
<td>71</td>
<td>94</td>
<td>87</td>
<td>101</td>
<td>88</td>
</tr>
<tr>
<td>DAST: PS&lt;sup&gt;c&lt;/sup&gt; (max = 15)</td>
<td>14.30 (0.90)</td>
<td>11</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>TEA: MS&lt;sup&gt;d&lt;/sup&gt;</td>
<td>13.00 (1.40)</td>
<td>16</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>14</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>TEA: ECD&lt;sup&gt;e&lt;/sup&gt;</td>
<td>12.38 (1.19)</td>
<td>13</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>6</td>
<td>4</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>SA&lt;sup&gt;f&lt;/sup&gt; (msec)</td>
<td>1.78 (11.38)</td>
<td>74</td>
<td>67</td>
<td>36</td>
<td>88</td>
<td>72</td>
<td>68</td>
<td>31</td>
<td>26</td>
</tr>
</tbody>
</table>

<sup>a</sup> Reading; standardised score
<sup>b</sup> Spelling; standardised score
<sup>c</sup> Phonological Segmentation; standardised score
<sup>d</sup> Map Search; standardised score
<sup>e</sup> Elevator Counting with Distraction
<sup>f</sup> Pre-cueing Attention Test: Shifting Attention. This score was obtained by averaging the RT-cost differences between moves toward and away from fixation in each visual field. Note that digits in **bold** indicate a significant difference when compared to the control group, \( p < 0.05 \).

on the spelling test. However, with the exception of cases SW and GM on both reading and spelling and case JM on reading, all were within the normal range on these tests (i.e., within one standard deviation of the standardised mean).
A high correlation between the literacy measures was observed ($r = 0.936$, $p < 0.001$). An average score was calculated to represent an average level of Literacy Attainment for further analysis.

As shown in Table 8.1.2, the performance of each ADys case was significantly poorer than the control group on the phonological segmentation task, and the performance of half of the ADys cases (RM, GM, TC and JM) was poorer on the Elevator Counting with Distraction. With only one exception (case TC), all of the ADys cases performed equally well as the control group on the Map Search task. The distribution of the scores on each task for each ADys and control is shown in Figure 8.2.

**Covert attention**

The RT analyses focused on two main areas: (1) RT to validly-cued targets; and (2) RT-cost of shifting attention from cued position to target position for invalidly-cued conditions (where RT-cost = invalid RT - valid RT for same target location). It was expected that the RT-cost would differ for the two types of invalidly-cued conditions. Invalid between-object shifts were expected to incur the greater RT-cost because the shift was to a different location in space as well as to a new object in space. Also, RT-costs of shifting attention toward and away from fixation were examined. Based on previous findings, it was expected that no difference would be found for the control group, but that ADys would demonstrate a greater RT-cost for shifting attention away from fixation. Experimental blocks in which participants responded to two or more catch trials were discarded, and trials in which RTs were less than 100 msec were treated as anticipations ($< 1\%$) and also excluded from the analyses. The RT analyses included only correct responses. To increase power of the analyses, data for upper and lower locations in the rectangles (which showed no significant difference in responses) were combined for each condition in each visual field.
Effects of cue validity

An omnibus analysis of variance (ANOVA), with cue type (valid or invalid), visual field (left or right) and rectangle orientation (horizontal or vertical) as factors, was carried out separately for the control group and each ADys case. A significant main effect of cueing was found for the control group and for all the ADys cases ($p < 0.01$), with one exception (case RM). Thus the RTs to validly-cued targets were faster than those for invalidly-cued targets, indicating an intact ability to covertly orient following a pre-cue in both visual fields. For case RM, a significant cue type by visual field interaction was found ($p < 0.001$), indicating an intact ability for covert orienting of attention only in the right visual field (RVF) and thus a difficulty with covert orienting following a pre-cue in the left visual field (LVF). The ability to covertly orient following a pre-cue was intact in both visual fields for all other cases and the control group. Analysis using modified $t$-tests revealed that the valid-cue RTs for each ADys case (although generally longer) were not significantly different to those of the control group in either visual field ($p > 0.05$).

Effects of type of attentional shift

An ANOVA was carried out on RT-costs with attentional shift type (within or between) and visual field (left or right) as factors (see Figure 8.1). As expected, a main effect of attentional shift type was significant for the control group and six of the ADys cases ($p < 0.01$). This supports the predicted finding that within-object shifts of attention would result in lower costs than between-object shifts in both visual fields. Cases TM and TC were the two exceptions for the ADys cases.

For TM there were no significant findings, indicating that the expected differences in costs of within-object and between-object attentional shifts for both visual fields were not evident ($p > 0.05$). For TC, a significant shift-type by visual field interaction was found ($p < 0.01$). Further analysis, using paired
sample \( t \)-tests, revealed a lack of discrimination for within-object and between-object shifts in the RVF only \((p < 0.05)\). Comparisons for each condition (LVF: within-object shift, LVF: between-object shift, RVF: within-object shift, RVF: between-object shift) were made for each ADys case compared with the control group using modified \( t \)-tests. Where an ADys case showed dissociations in the two visual fields for each type of invalid cue, and/or dissociations for each type of attentional shift in each visual field, these were compared to the control group using a Revised Standardized Difference Test. Compared to the control group, seven ADys cases (exception case TM) demonstrated some evidence of higher costs of between-object shifts of attention, but these higher costs
reached statistical significance for only five cases (GM, JM, SM, TC, and RM). Cases GM, JM and SM showed significantly higher costs of between-object shifts of attention in both visual fields, whereas significantly higher costs of between-object shifts of attention were shown by case TC only in the LVF, and case RM only in the RVF ($p < 0.05$). The important finding is that three ADys cases (TC, RM and TM) show a different pattern of responding to that of the control group and the other ADys cases. These ADys cases demonstrate that expected differences in RT-costs for within- and between-object shifts of attention are not always evident: TM (for both visual fields), RM (for the LVF) and TC (for the RVF). The results for case TM are consistent with a lack of specific object-based attentional processing. It appears that he relies entirely on spatial processes when attending to stimuli. The results for RM are consistent with some form of global processing of LVF stimuli whereby a cue provides an alerting function but is unable to focus attention, resulting in no difference in RTs between validly- and invalidly-cued targets or between the two types of invalidly-cued targets (within- and between-object shifts of attention). The results for TC indicate a lack of object-based attentional processes for stimuli in the RVF only.

**Effects of direction of attentional shift**

An omnibus analysis of variance (ANOVA), with direction of attentional shift relative to fixation (toward or away) and visual field (left or right) as factors, was carried out separately for the control group and each ADys case. There were no significant findings for the control group; indicating shifts toward and away from fixation did not show different costs in the two visual fields. With the exception of case SW, a significant main effect of shift direction was found for each ADys case ($p < 0.05$). Analyses using paired sample $t$-tests showed these ADys cases to have significantly lower RT-costs associated with shifts toward fixation compared with shifts away from fixation in both visual fields ($p < 0.001$). For case SW, this comparison was significant in the RVF only.
(\(p < 0.05\)). Comparisons of each condition were made between each case and the control group using modified \(t\)-tests. In comparison with the control group, ADys cases GP, JM, RM and TC showed significantly lower costs of attention shifts toward fixation in both visual fields, cases SW and GM showed significantly lower costs of attention shifts toward fixation in the RVF only, and case SM showed significantly lower costs of attention shifts toward fixation in the LVF only (\(p < 0.05\)). Compared to the control group, ADys cases GP, JM, SM and GM showed significantly higher costs of attention shifts away from fixation in both visual fields (\(p < 0.001\)), case SW showed significantly higher costs of attention shifts away from fixation in the RVF only, and TC showed significantly higher costs of attention shifts away from fixation in the LVF only (\(p < 0.001\)). (Note: ADys cases TM, RM and TC showed higher costs associated with attention shifts away from fixation in the RVF, compared to the control group, however these did not reach significance.) A measure of overall difficulty in shifting covert visual attention was obtained by averaging the RT-cost differences between moves toward and away from fixation in each visual field (see Table 8.1.2). Compared to the control group, each ADys case demonstrated poorer ability to shift attention away from fixation. The distribution of scores for both ADys and controls is shown in Figure 8.2.

**Summary of covert attentional processing in adults with dyslexia**

The control group and all ADys cases (except RM) demonstrated an ability to covertly orient attention following a pre-cue in both visual fields. Case RM showed an overall difficulty in orienting to stimuli presented in the LVF. Three ADys cases (GM, JM and SM) demonstrated larger RT-costs associated with between-object shifts in both visual fields compared to the control group. Three ADys cases (TM, RM and TC) demonstrated different patterns of response to within- and between-object shifts compared to both the control group and the other ADys cases, specifically, the predicted differences in RT-costs for within- and between-object shifts of attention were not evident.
for TM (for both visual fields), TC (for the RVF) and RM (for the LVF). The RT-costs of shifts of attention away from fixation were significantly greater than RT-costs of shifts of attention toward fixation for ADys cases.
Correlational analyses of measures

Relationships between some of the measures studied are suggested by the heterogeneity observed in Figure 8.2. Although the number of participants in the present study does not allow for powerful correlation analyses, there are interesting findings shown in Table 8.2. Namely, significant correlations are obtained. Not surprisingly, given that literacy attainment measures intrinsically rely on skills of phonology, the largest correlation occurs between this measure and the phonological awareness measure \( r = 0.789, p < 0.001 \). The measure of overt attention did not correlate with any of the other measures.

Table 8.2: Correlations between variables, and standard multiple regression of covert attention and auditory memory measures on phonological ability.

<table>
<thead>
<tr>
<th>Variables</th>
<th>LA(^a)</th>
<th>PA(^b)</th>
<th>OA(^c)</th>
<th>AM(^d)</th>
<th>B</th>
<th>( \beta )</th>
<th>( sr^2 ) (unique)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>0.789**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>0.213</td>
<td>0.218</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM</td>
<td>0.600*</td>
<td>0.573*</td>
<td>0.496</td>
<td></td>
<td>0.208</td>
<td>0.208</td>
<td>0.030</td>
</tr>
<tr>
<td>CA(^e)</td>
<td>0.708**</td>
<td>0.776**</td>
<td>0.099</td>
<td>0.552*</td>
<td>0.006</td>
<td>0.660</td>
<td>0.304</td>
</tr>
</tbody>
</table>

\( R^2 = 0.63 \)  \( \text{Adj. } R^2 = 0.58 \)  \( R = 0.80^{**} \)

\( a. \) Literacy Attainment  
\( b. \) Phonological Awareness  
\( c. \) Overt Attention  
\( d. \) Auditory Memory  
\( e. \) Covert Attention

\( *p < 0.05; **p < 0.01, \) no correction applied. Note that positive correlations indicate that more severe deficits on one measure are related to more severe deficits on the correlated measure.
The question as to how much of a contribution the other measures make to phonological ability was addressed by running a standard multiple regression between Phonological Awareness (Dependent Variable) and the Independent Variables (IV): Covert Attention and Auditory Memory (which showed significant correlations with each other). Only Covert Attention contributed significantly to the regression, \( t(2, 13) = 3.27, p < 0.01 \), accounting for 30% of unique variance. Approximately 27% of variance is shared by the two IVs. Although the bivariate correlation between Phonological Awareness and Auditory Memory measures was reliably different to zero \( (p < 0.01) \), this relationship appears to be mediated by Covert Attention. This is suggested by the shared variance and significant correlation between Auditory Memory and Covert Attention.

### 8.1.3 Discussion

All of the individual adults with dyslexia (ADys) showed performance deficits on a task examining phonological awareness, although literacy attainment did not appear seriously impaired. This is consistent with the findings of previous studies of adults with dyslexia (e.g., Bruck, 1992; Brunswick, McCrory, Price, Frith, and Frith, 1999; Fawcett and Nicolson, 1995a; Felton, Naylor, and Wood, 1990; Paulesu, Frith, Snowling, Gallagher, Morton, Frackowiak, and Frith, 1996), in that phonological processing difficulties persist even when literacy skills are in the average range. This may be the result of individual literacy training and the ability to use an orthographic strategy (sight vocabulary). Four of these ADys cases (RM, GM, TC and JM) also demonstrated an auditory memory difficulty. Each ADys case performed more poorly than a group without dyslexia on a covert visual attention task. For case RM there was a specific problem with responding to a valid pre-cue: RMs performance was not significantly improved for detection of a target following a valid cue (compared to an invalid pre-cue) in the LVF. This finding suggests a possible global processing of stimuli in the LVF. This diffuse distribution of visual pro-
cessing has also been reported in children with dyslexia (Facoetti and Molteni, 2001). An examination of the space-based and object-based components of the covert attention task determined difficulties for two ADys cases (TM and TC). Case TM appeared to rely entirely on spatial processes when attending to stimuli, since there was no difference in performance for within-object shifts of attention and between-object shifts of attention. Case TC showed a reliance on spatial processes for stimuli presented in the RVF. These difficulties with shifting attention between objects, specifically in the RVF may represent a specific left hemisphere deficit (see Egly, Driver, and Rafal, 1994a; Egly, Rafal, Driver, and Starrveveld, 1994b). In addition, all of the ADys cases showed a specific difficulty in engaging stimuli parafoveally in the RVF. This was demonstrated by increased response time costs for shifts of attention away from fixation together with reduced response time costs for shifts of attention toward fixation (compared to the control group). In a similar context, it has been reported that children with poor reading skills do not appear to make use of peripheral cues to rapidly orient their visual attention (Brannan and Williams, 1987).

**Contribution of attention and working memory to phonological awareness**

The covert visual attention measure showed a significant impact on phonological ability. While all ADys cases demonstrated a deficit on this covert attentional measure, only one ADys case (TC) also demonstrated a deficit on the overt attentional measure. It appears that when eye movements are allowed in tasks examining visual attention, individuals with dyslexia may perform as well as those who do not have dyslexia. This may provide some explanation for the inconsistent findings of performance deficits on visual search tasks by individuals with dyslexia in studies, which may not have controlled for eye movements (e.g., Casco and Prunetti, 1996). These findings suggest phonological deficits may occur in the absence of overt visual attention difficulties.
It should be noted that in addition to allowing eye movements, the overt attention task used in this study also allowed the use of an external aid (pen) in guiding attention. This may have confounded the present findings. Auditory short-term memory performance was not a significant predictor of phonological ability. This measure showed a significant relationship with the covert visual attentional measure, thus its effect on phonological ability may be mediated by some common process it shares with visual selective attention. Indeed, the short-term memory measure used in this study also contains a component of selective auditory attention. Both auditory and visual inputs have been shown to converge on the parietal cortex (Farah, Wong, Wong, Monheit, and Morrow, 1989), and the common process in directing attention in both visual and auditory modalities may be parietal cortex function.

In summary, the findings confirm the previous evidence that phonological processing deficits persist in adults with dyslexia, even when major reading and spelling deficits are no longer present. The results of this study also suggest a multifactorial basis for dyslexia, where both covert visual attentional deficits in addition to impaired phonological skills contribute to the reading difficulties experienced in dyslexia. The phonological deficit can arise in the absence of an auditory memory deficit, which does not exert an independent effect over that shared with visual attentional processes. The nature of these relationships requires further study.
Chapter 9

Specificity of attentional deficit

Based on the results presented in the previous chapters of this thesis it appears undeniable that a disruption to visual attentional processes plays a role in dyslexia. However, it remains unclear whether individuals with dyslexia have a general attentional difficulty, or a more specific deficit. For example, difficulties have been demonstrated in maintaining attentional focus (Facioetti, Paganoni, Turatto, Marzola, and Mascetti, 2000b), orienting attention (e.g., Brannan and Williams, 1987; Buchholz and Aimola Davies, 2005; Facioetti and Molteni, 2001; Facioetti, Paganoni, and Lorusso, 2000a) and shifting attention (e.g., Buchholz and McKone, 2004; Vidyasagar, 1999).

In this chapter the visual attentional processing in adults with developmental dyslexia who show phonological problems is examined. These were individuals with a high average-IQ and a demonstrated ability to perform on tasks having high concentration demands. Performance was measured on two spatial cueing tasks: a detection task and a discrimination task.
Assessing visual attentional processes in dyslexia

Visual attention acts as a filter for information, reducing the amount of stimuli in the environment to a manageable quantity for processing by a limited capacity system. Posner and Petersen (1990) proposed the existence of three independent attentional networks with specific functions for alerting, orienting and executive control. Alerting is defined as preparing and maintaining a state of readiness to detect a stimulus, orienting selects particular sensory information by shifting and reducing the attentional focus (see also Castiello and Umilta, 1990; Posner, Walker, Friedrich, and Rafal, 1987; Turatto, Benso, Facoetti, Galfano, Mascetti, and Umilta, 2000), and executive control is the process of deciding about the relevance of presented stimuli to the task requirements (see also Steinman, Steinman, and Lehmkuhle, 1995).

It is possible to examine the separate attentional effects of alerting, orienting and executive control using a single test that combines spatial cueing with a flanker task (Fan, McCandliss, Sommer, Raz, and Posner, 2002). In this task, an individual must determine the direction of a centrally positioned arrow (that can occur above or below fixation), which may be accompanied by flanker arrows that point either in the same direction or in the opposite direction. Attentional performance on this discrimination task is measured by how response times are influenced by alerting cues, spatial cues and flankers. Bednarek and colleagues (2004) examined these effects in children with dyslexia and determined that when compared to an age-matched control group they showed difficulties only in executive control. Rizzolatti et al. (1987) also propose that the response time deficits shown by individuals with dyslexia on tasks examining covert attention is due to deficient executive control, that is, suppressing the executive decision to move the eyes results in slowed responses to stimuli.

The ability to covertly orient attention is typically investigated by using a spatial cueing experiment, in which attention is oriented without eye movements (Posner, 1980). The method requires presentation of a spatial cue fol-
lowed by a target, either in the same position as the cue (valid) or in an alternative location to the cue (invalid). The cue effect is shown on this detection task when response times of the valid-cue condition are faster than the invalid-cue condition. This difference in response time for the two conditions provides a measure of orienting ability. Both adults and children with dyslexia have shown orienting difficulties on this type of spatial cueing task (Brannan and Williams, 1987; Buchholz and Aimola Davies, 2005; Facoetti et al., 2003; Facoetti and Molteni, 2001; Facoetti et al., 2001, 2000a,b).

Facoetti and colleagues have proposed that the orienting difficulties observed in their studies of children with dyslexia are the result of a diffusely distributed attentional system (Facoetti et al., 2003; Facoetti and Molteni, 2001; Facoetti et al., 2001, 2000a,b). Specifically, increasing eccentricity from central fixation did not lead to the expected increase in response times for stimulus detection. This was interpreted as evidence for a deficit in mechanisms inhibiting laterally distracting information... (Facoetti and Molteni, 2001, pg 353). These researchers observed that children with dyslexia showed longer response times for peripheral targets with a large cue (7.5°) than for those with a smaller cue (2.5°), at short stimulus onset asynchrony (SOA). This pattern was similar to the response pattern of the control group. Thus both groups demonstrated a cue size effect. However, while the control group showed improved performance for both cue sizes and maintained a cue size difference in response times at longer SOA, the children with dyslexia only showed improved target detection for the larger cue size. This, together with the lack of a cueing effect for peripheral stimuli suggested a difficulty in maintaining the size of the attentional focus in the periphery (Facoetti et al., 2000b).

In a recent case study of adults with dyslexia (Buchholz and Aimola Davies, 2005), using a Posner-type cueing paradigm, it was found that the ability to orient attention was dependent on the distance from fixation of cue presentation. These individuals showed difficulty in orienting attention in a peripheral location whereas orienting ability appeared intact (although slower than
the control group) close to fixation. This suggests that, for these adults with
dyslexia, the peripheral cue may not capture and focus attention so that atten-
tion remains diffuse. When these results are compared with those of Facoetti
and colleagues, it appears that the attentional difficulties associated with ori-
enting in the periphery in children persist into adulthood.

In this study, the individual performance of five cases of adult dyslexia on
two spatial cueing tasks (a detection task and a discrimination task) will be
compared to a control group. I aim to investigate the attentional effects of
alerting, orienting and executive control. It is predicted that alerting will be
intact for each case of adult dyslexia, while deficits in executive control may
be present. Difficulties in orienting are expected, specifically with relation to
peripheral as compared with foveal processing.

9.1 Experiment 6

It has been suggested that the distribution of attention, both within and
across the left and right visual fields, is impaired in individuals with dyslexia.
In this experiment, I considered the possibility that this difficulty may be lim-
ited to the orienting effect of attention. The Egly et al. (1994b) precueing
paradigm was chosen to specifically examine the effects of eccentricity. In ad-
dition to allowing space-based and object-based components of attention to be
studied (see Buchholz and Aimola Davies, 2005), this paradigm allows orient-
ing effects to be examined both within and between two different eccentricities
(centred at either 3° and 6.5°).

9.1.1 Method

Participants

Five ADys cases from the experimental pool: GP, SM, SW, GM and TC
participated in this experiment (cases TM, RM and JM were unavailable).
The control group consisted of 16 adults with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.

Procedure

Attentional orienting was assessed using the Egly et al. (1994b) precueing paradigm, as presented for Experiment 3.

9.1.2 Results

Responses to catch trials and missed responses were not analysed. Trials with response times (RTs) faster than 100 msec or more than 2.5 standard deviations from the individuals mean for that condition were defined as outliers and excluded from further analysis. This resulted in less than 1% of data being removed for any individual. Summary data for no-cue, invalid-cue and valid-cue trials are presented in Table 9.1.

Given that assumptions of Analysis of Variance (ANOVA) could be violated if the control group were compared directly with the dyslexia group, due to an expected greater variance in the clinical sample (e.g., Cornelissen, Richardson, Mason, Fowler, and Stein, 1995; Roach, Edwards, and Hogben, 2004; Tallal, 1980; Witton, Stein, Stoodley, Rosner, and Talcott, 2002), data analysis proceeded as follows: Control group analysis of individual participant mean RT data for each condition using ANOVA. Individual dyslexia case raw RTs were then analysed with ANOVA, which was analytically sound since RT skew in all conditions was in the same direction within the individual case data (Tabachnick and Fidell, 2001). Finally, individual case to control group comparisons were made, employing Crawford and Howells modification of the one-sample $t$-test (see Chapter 3).
Table 9.1: Summary RTs (msec) of no-cue, invalid-cue and valid-cue conditions.

<table>
<thead>
<tr>
<th>Cue Condition</th>
<th>No-cue</th>
<th>Invalid within-eccentricity</th>
<th>Invalid across-eccentricity</th>
<th>Valid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target Eccentricity</strong></td>
<td>3°</td>
<td>6.5°</td>
<td>3°</td>
<td>6.5°</td>
</tr>
<tr>
<td><strong>RVF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control: <em>Mean</em></td>
<td>491.56</td>
<td>506.84</td>
<td>346.25</td>
<td>347.82</td>
</tr>
<tr>
<td><em>s.d.</em></td>
<td>60.47</td>
<td>59.97</td>
<td>52.58</td>
<td>53.58</td>
</tr>
<tr>
<td>GM</td>
<td>548.17</td>
<td>577.65</td>
<td>437.79</td>
<td>414.25</td>
</tr>
<tr>
<td>GP</td>
<td>554.42</td>
<td>601.58</td>
<td>432.04</td>
<td>429.67</td>
</tr>
<tr>
<td>SW</td>
<td>491.96</td>
<td>499.83</td>
<td>392.17</td>
<td>351.79</td>
</tr>
<tr>
<td>TC</td>
<td>539.63</td>
<td>570.25</td>
<td>418.21</td>
<td>391.33</td>
</tr>
<tr>
<td>SM</td>
<td>582.50</td>
<td>628.67</td>
<td>407.33</td>
<td>394.08</td>
</tr>
<tr>
<td><strong>LVF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control: <em>Mean</em></td>
<td>490.61</td>
<td>512.74</td>
<td>349.26</td>
<td>353.77</td>
</tr>
<tr>
<td><em>s.d.</em></td>
<td>59.42</td>
<td>56.14</td>
<td>58.74</td>
<td>60.47</td>
</tr>
<tr>
<td>GM</td>
<td>549.08</td>
<td>591.25</td>
<td>441.17</td>
<td>412.75</td>
</tr>
<tr>
<td>GP</td>
<td>566.38</td>
<td>603.04</td>
<td>468.25</td>
<td>423.00</td>
</tr>
<tr>
<td>SW</td>
<td>483.83</td>
<td>512.42</td>
<td>374.25</td>
<td>357.38</td>
</tr>
<tr>
<td>TC</td>
<td>528.00</td>
<td>574.38</td>
<td>412.96</td>
<td>398.65</td>
</tr>
<tr>
<td>SM</td>
<td>555.17</td>
<td>575.70</td>
<td>420.17</td>
<td>407.25</td>
</tr>
</tbody>
</table>

Invalid-within-eccentricity: cue and target appear at the same eccentricity but different locations (high or low).
Invalid-across-eccentricity: cue and target appear at the same relative location but different eccentricities.
Target detection at each eccentricity

An initial analysis was carried out on the no-cue data to examine the participants’ ability to detect targets without alerting and orienting effects on attention. For the control group, a two-way ANOVA on visual field (left or right) and eccentricity (3° or 6.5°) was carried out on group RT means for each condition. The only significant finding was a main effect of eccentricity ($F(1,15) = 15.89, p = 0.001$), indicating that RTs to targets at 6.5° were longer than at 3° in both visual fields (see Table 9.1).

The data (raw RTs) was then analysed for each ADys case in turn. Two-way ANOVAs determined that each case showed the same pattern of response as the control group. A significant main effect of eccentricity ($p < 0.01$), indicating longer RTs to targets at 6.5° than at 3°. Case SM also showed a main effect of visual field ($p < 0.01$), indicating faster RTs in the LVF then in the RVF. No other significant effect or interaction was observed for any case.

An size of the eccentricity effect was calculated by subtracting the RT to targets with no-cue at 3° eccentricity from the RT to targets with no-cue at 6.5° eccentricity. The distribution of mean difference scores for the control group and each ADys case in each visual field is shown in Figure 9.1. Planned comparisons of the eccentricity effect, made between the control group and each ADys case, showed no significant differences in both visual fields ($p > 0.05$). Thus, all the ADys cases respond as well as the control group to a target presented without cueing at either eccentricity within each visual field.

Effect of cues on response time

From Table 9.1 it appears that both the valid and invalid cues improve performance since the RTs are much lower for both of these conditions compared to the no-cue condition. For the control group, a 3-way ANOVA was carried out, with visual field (left or right), eccentricity (3° or 6.5°) and cue type (either no
Chapter 9: Specificity of attentional deficit

Figure 9.1: No-cue condition: Effects of eccentricity (right and left visual field) for the control group (mean and standard deviation), and the distribution of means for the adults with dyslexia (ADys). No ADys case was significantly different to the control group. Note that the eccentricity effect is based on RT at 3° eccentricity subtracted from the RT at 6.5° eccentricity.

cue vs valid) as factors. Significant main effects of cue type \(F(1, 15) = 230.93, p < 0.001\) and eccentricity \(F(1, 15) = 19.32, p = 0.001\) were found. These results indicate overall longer RTs for targets preceded by no cue than for targets preceded by a valid cue, and longer RTs to targets presented at 6.5° than 3° eccentricity. A significant interaction between cue-type and eccentricity was also observed \(F(1, 15) = 9.62, p < 0.01\), indicating that the effect of eccentricity was greater for the no-cue condition than the valid-cue condition.

The data was then analysed for each ADys case in turn. Significant main effects of cue type and eccentricity were found for all ADys cases, as well as a significant interaction between cue-type and eccentricity \(p < 0.05\). These results indicated longer RTs to targets preceded by no cue than a valid cue, longer RTs to targets at 6.5° than 3° eccentricity, and a greater effect of ec-
centricity for the no-cue condition than the valid-cue condition. Thus, for the no-cue and valid-cue condition, it appears that the pattern of performance by the ADys cases was similar to the control group.

A further 3-way ANOVA was carried out on control group data, with visual field (left or right), eccentricity ($3^\circ$ or $6.5^\circ$) and cue type (either no cue vs invalid) as factors. [Note: the invalid trials used in this analysis were those where cue and target appeared at same eccentricity but different locations, that is, within-eccentricity shifts of attention were required.] Significant main effects of cue type, $F(1, 15) = 108.33$, $p < 0.001$, and eccentricity, $F(1, 15) = 12.90$, $p < 0.01$, were found. These results indicate overall longer RTs for targets preceded by no cue than for targets preceded by an invalid cue, and longer RTs to targets presented at $6.5^\circ$ than $3^\circ$ eccentricity.

The data was then analysed for each ADys case in turn. A significant main effect of cue type as well as a significant interaction between cue-type and eccentricity ($p < 0.05$) were found for all ADys cases. Similar to the control group, these results indicated overall longer RTs to targets preceded by no cue than an invalid cue, and RTs to targets with no cue were longer in the periphery ($6.5^\circ$) than closer to fixation ($3^\circ$). In contrast to the control group, RTs to targets following an invalid cue were shorter in the periphery than close to fixation.

Inspection of Table 9.1 also shows that all ADys cases demonstrated generally longer RT latencies than the control group. Thus, it appears that ADys performance differs to the control group in response to targets preceded by an invalid cue. This is examined further in the next section.

---

1Invalid shifts at each eccentricity in this analysis include vertical rectangle within-object shifts and horizontal rectangle between-object shifts, e.g., cue and target presented at $3^\circ$ eccentricity in different horizontal rectangles (upper or lower of the same VF), or at $3^\circ$ eccentricity at different locations (upper or lower of the same VF) within the same vertical rectangle. This data provides a measure of cue effect within each given eccentricity, allowing a direct comparison with the no-cue condition.
Attentional orienting

The RT cost of orienting attention to an invalid cue is calculated by subtracting the RTs for the valid-cue condition from those of the invalid-cue condition with the same target location, that is, visual field, eccentricity and location. Both cue types provide alerting and broad lateral orienting effects on attention (as shown by the improved performance relative to no-cue in the previous analysis), but only the valid cue provides correct predictive spatial information because the individual does not need to disengage from an invalid cue position to detect the target. The ability to orient attention is indicated by a positive RT cost.

Orienting at each eccentricity (3° and 6.5°) was examined in two ways. First, by examining the RT costs associated with shifts of attention occurring within a given eccentricity. That is, where the invalid conditions required the cue and target to appear in the same visual field, within the same eccentricity (3° only or 6.5° only) but at different locations (either upper or lower VF). Second by examining the RT costs associated with shifts of attention across eccentricities. That is, where the invalid condition required the cue and target to appear in the same visual field, at different eccentricities (3° or 6.5°) but at the same relative location (upper VF only or lower VF only). A summary of the RT costs of orienting following an invalid cue in these two conditions (for both the control group and ADys cases) is shown in Table 9.2.

Orienting attention: within-eccentricity

For the control group, a two-way analysis of variance (ANOVA) on visual field (left or right) and target eccentricity (3° or 6.5°) was carried out for RT costs associated with shifting attention following an invalid cue within each eccentricity. There were no significant main effects or interactions found ($p > 0.20$).
Table 9.2: Summary orienting costs (msec) associated with attention shifts within- or across-eccentricity.

<table>
<thead>
<tr>
<th>Target Eccentricity</th>
<th>Orienting Cost of Attention Shift</th>
<th>within-eccentricity</th>
<th>across-eccentricity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3°</td>
<td>6.5°</td>
<td>3°</td>
</tr>
<tr>
<td><strong>RVF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control: Mean</td>
<td>43.50</td>
<td>43.69</td>
<td>30.90</td>
</tr>
<tr>
<td>s.d.</td>
<td>19.53</td>
<td>12.78</td>
<td>15.14</td>
</tr>
<tr>
<td>GM</td>
<td>56.81</td>
<td>15.44</td>
<td>10.15</td>
</tr>
<tr>
<td>GP</td>
<td>44.98</td>
<td>26.94</td>
<td>11.36</td>
</tr>
<tr>
<td>SW</td>
<td>49.30</td>
<td>3.96</td>
<td>0.84</td>
</tr>
<tr>
<td>TC</td>
<td>49.20</td>
<td>11.45</td>
<td>20.70</td>
</tr>
<tr>
<td>SM</td>
<td>39.68</td>
<td>14.02</td>
<td>0.18</td>
</tr>
<tr>
<td><strong>LVF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control: Mean</td>
<td>44.05</td>
<td>43.02</td>
<td>35.70</td>
</tr>
<tr>
<td>s.d.</td>
<td>21.51</td>
<td>18.61</td>
<td>22.08</td>
</tr>
<tr>
<td>GM</td>
<td>54.83</td>
<td>16.80</td>
<td>27.91</td>
</tr>
<tr>
<td>GP</td>
<td>60.79</td>
<td>1.45</td>
<td>-3.71</td>
</tr>
<tr>
<td>SW</td>
<td>32.35</td>
<td>18.89</td>
<td>23.89</td>
</tr>
<tr>
<td>TC</td>
<td>43.79</td>
<td>30.94</td>
<td>6.04</td>
</tr>
<tr>
<td>SM</td>
<td>24.55</td>
<td>22.75</td>
<td>-5.11</td>
</tr>
</tbody>
</table>

Within-eccentricity refers to the cost of orienting attention associated with shifting attention to different locations within the same eccentricity and visual field. Across-eccentricity refers to the cost of orienting attention associated with shifting attention to different eccentricities but in the same relative location and visual field.

Inspection of Table 9.2 shows that compared to the control group, all ADys cases demonstrated lower RT costs of shifting attention within 6.5° eccentricity compared to within 3° eccentricity in both visual fields. The significance of this apparent eccentricity effect was examined in each visual field for each ADys case, compared against the control group. The size of the eccentricity effect was calculated by subtracting the RT cost within 6.5° eccentricity from the RT cost within 3 eccentricity. The distribution of difference scores for the
control group and ADys cases in each visual field is shown in Figure 9.2. The eccentricity effect of each ADys case was tested for significance against the control group using the Crawford and Howell (1998) modified $t$-test. Case GM showed a significantly different eccentricity effect in both visual fields, while for cases SW and TC this was only significant in the RVF and for case GP in the LVF. Thus, for these individuals, orienting attention within $6.5^\circ$ eccentricity resulted in lower RT costs, which can be interpreted as being relatively more difficult than orienting attention within $3^\circ$ eccentricity, having higher RT costs (all $p < 0.05$.)

Figure 9.2: Invalid-within condition: effects of eccentricity (right and left visual field) for the control group (mean and standard deviation), and the distribution of means for the adults with dyslexia (ADys). Cases that were significantly different to the control group are identified. Note that the eccentricity effect is based on RT cost at $3^\circ$ eccentricity subtracted from the RT cost at $6.5^\circ$ eccentricity.
Orienting attention: across-eccentricity

For the control group, a two-way analysis of variance (ANOVA) on visual field (left or right) and target eccentricity (3° or 6.5°) was carried out for RT costs associated with shifting attention across eccentricities. There were no significant main effects or interactions found ($p > 0.20$).

Inspection of Table 9.2 shows that compared to the control group, all ADys cases demonstrated lower RT costs with a cue at 6.5° and target at 3°, and higher RT costs with a cue at 3° and target at 6.5°. The significance of this apparent eccentricity effect was examined in each visual field for each ADys case, compared against the control group. The size of the eccentricity effect was calculated by subtracting the RT cost of a cue at 3° eccentricity from the RT cost of a cue at 6.5° eccentricity. The distribution of difference scores for the control group and ADys cases in each visual field is shown in Figure 9.3.

![Figure 9.3: Invalid-across condition: effects of eccentricity (right and left visual field) for the control group (mean and standard deviation), and the distribution of means for the adults with dyslexia (ADys). Cases that were significantly different to the control group are identified. Note that the eccentricity effect is based on RT cost at 3° eccentricity subtracted from the RT at 6.5° cost eccentricity.](image-url)
The eccentricity effect of each ADys case was tested for significance against the control group using the Crawford and Howell (1998) modified t-test. All cases (except case SW) showed a significantly larger eccentricity effect in both visual fields. For case SW this was only significant in the RVF (all $p < 0.05$).

**Summary of results**

All ADys cases showed overall benefits for target detection following cue presentation. However, compared to the control group, a different pattern of results was observed for attentional orienting. Specifically, each case demonstrated some difficulty associated with orienting to a cue at 6.5° eccentricity, particularly in the RVF.

### 9.2 Experiment 7

The Attentional Network Test (ANT; Fan et al., 2002) was employed to examine the alerting, orienting and executive function of attention in ADys cases. The ANT is a discrimination task that examines attentional effects of alerting and orienting very close to fixation (1° eccentricity).

#### 9.2.1 Method

**Participants**

Five ADys cases from the experimental pool: GP, SM, SW, GM and TC participated in this experiment (cases TM, RM and JM were unavailable). The control group consisted of eleven paid volunteers with no history of reading difficulties. Psychometric assessment results were presented in Chapter 3.
Apparatus and procedure

Stimuli were presented using PsyScope on an Apple computer running OS-9 with a 17-inch computer screen and a refresh rate of 85 Hz. Participants viewed the screen from a distance of approximately 65 cm.

Participants were required to fixate on a central cross (0.4° × 0.4°) which was present throughout each trial. Stimuli appeared approximately 1° of visual angle above or below fixation, and appeared in black on an off-white background (see Figure 9.4). The task was to press one of two buttons on a keyboard to indicate whether a target arrow, positioned directly above or below the fixation cross, pointed to the left or to the right. The target arrow could appear alone (neutral condition) or be flanked on either side by two arrows pointing in the same direction (congruent condition) or in a different direction (incongruent condition). A single arrow consisted of 0.55° visual angle and the contours of adjacent arrows were separated by 0.06° of visual angle. There were also four cueing conditions: no cue (fixation cross only), centre-cue (asterisk at fixation), double-cue (asterisk above and below fixation at two possible target locations) and valid-cue (asterisk at target location). The asterisk cue subtended 0.4° × 0.4° of visual angle.

Each trial consisted of a fixation period of random variable duration (400–1600 msec), followed by a cue (if present) for 100 msec, then another fixation period of 400 msec followed by the stimulus which remained on screen until the participant responded, or a maximum of 1700 msec. A post-target fixation period followed which was calculated by subtracting the first fixation period and response time from 3500 msec. Each trial lasted a total maximum of 4000 msec. The experimental session consisted of a 24-trial practice block in which participants received feedback on their accuracy, and two experimental blocks of trials with no feedback. Each experimental block consisted of 96 randomly presented trials (4 cue conditions × 2 target locations × 2 target directions × 3 flanker conditions × 2 repetitions). Participants were instructed to respond
9.2.2 Results

Trials with RTs faster than 300 msec or more than 2.5 standard deviations from the individuals mean were excluded for the analysis of accuracy. Incorrect trials were further excluded for RT analysis. This resulted in less than 1% of
data being removed for any individual. Analyses followed the same sequence as for Experiment 6.

**Response time and accuracy score analyses**

For the control group, a preliminary repeated-measures ANOVA on RT data was carried out for the arrow with neutral flanker in a no-cue condition, with arrow direction (right and left) and target location (above centre and below centre) as factors. No significant main effects or interactions were found ($p > 0.05$). Data was then analysed for each ADys case in turn. No significant main effects or interactions were found ($p > 0.05$), indicating that the general perceptual abilities (e.g., distinguishing right-facing arrows from left-facing arrows) of each ADys case was similar to that of the control group. Note that in subsequent analyses, data were pooled across target-arrow direction and location. A summary of accuracy and RT data is presented in Table 9.3. Comparisons between the control group and each ADys case of overall performance, using the Crawford and Howell (1998) modified $t$-test, indicated that RTs were significantly longer for all ADys cases (except GP) ($p < 0.05$).

**Overall accuracy**

For the control group, a repeated-measures ANOVA of accuracy data was performed with flanker (neutral, congruent, incongruent) and cue type (no cue, centre, double, spatial) as factors. Only a significant main effect of flanker was found ($F(2, 20) = 4.84, p < 0.02$). This finding indicates decreased accuracy between the congruent (99%) and incongruent (97%) conditions ($p < 0.05$), but there were no significant differences between accuracy in these conditions and the neutral condition (98%; $p > 0.05$). Data was analysed for each ADys case in turn. A significant main effect of flanker was found for all ADys cases ($p < 0.05$). For all ADys cases (except GM), this main effect indicates decreased accuracy in the incongruent-flanker condition in relation to the neutral- and congruent-flanker conditions. For case GM, accuracy was reduced for both
Table 9.3: Accuracy and RTs for the control group (mean and s.d.) and each ADys case as a function of flanker condition.

<table>
<thead>
<tr>
<th></th>
<th>Flanker Condition</th>
<th>Control mean (s.d.)</th>
<th>GM</th>
<th>GP</th>
<th>SW</th>
<th>TC</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (% correct)</td>
<td>neutral</td>
<td>98 (1)</td>
<td>100</td>
<td>98</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>congruent</td>
<td>99 (1)</td>
<td>98</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>92**</td>
</tr>
<tr>
<td></td>
<td>incongruent</td>
<td>97 (1)</td>
<td>98</td>
<td>90**</td>
<td>96</td>
<td>98</td>
<td>68***</td>
</tr>
<tr>
<td>RT (msec)</td>
<td>neutral</td>
<td>541 (82)</td>
<td>718*</td>
<td>540</td>
<td>597</td>
<td>579</td>
<td>658</td>
</tr>
<tr>
<td></td>
<td>congruent</td>
<td>605 (76)</td>
<td>848*</td>
<td>591</td>
<td>682</td>
<td>649</td>
<td>928**</td>
</tr>
<tr>
<td></td>
<td>incongruent</td>
<td>705 (101)</td>
<td>905*</td>
<td>684</td>
<td>773</td>
<td>753</td>
<td>1186**</td>
</tr>
</tbody>
</table>

Significance of differences between case scores and the control group means: *p < 0.05, **p < 0.01, ***p < 0.001.

congruent-flanker (98%) and incongruent-flanker (98%) conditions relative to the neutral-flanker (100%) condition (see Table 9.3). No other significant effects were found. Accuracy of each ADys case was compared with the control group in each flanker condition using Crawford and Howells (1998) modified $t$-test. Case SM showed significantly lower accuracy compared to the control group, for both the incongruent-flanker condition (68% vs 97%; $p < 0.001$), and the congruent-flanker condition (92% vs 99%; $p < 0.001$). This may indicate a processing difficulty resulting from the increase in stimuli presented that is, two flankers each side of the target in the congruent- and incongruent-flanker conditions compared with none in the no-flanker condition) and/or deficient executive control. Case GP demonstrated significantly lower accuracy for the incongruent-flanker condition only (90% vs. 97% for the control group; $p < 0.001$), indicating that this processing difficulty is more likely associated with deficient executive control (conflict resolution) than the amount of information needing to be processed.
Overall response time

For the control group, a repeated-measures ANOVA of RT data was performed with flanker (neutral, congruent, incongruent) and cue type (no cue, centre, double, spatial) as factors. A significant main effect of flanker was found ($F(2, 20) = 136.35, p < 0.001$). The fastest RTs occurred in the neutral condition and the slowest RTs occurred in the incongruent-flanker condition (see Table 9.3). A significant main effect of cue type was also found ($F(2, 20) = 37.3, p < 0.001$). The fastest RTs occurred in the spatial-cue condition followed by double- and centre-cue conditions, and the slowest responses in the no-cue condition. This suggests that performance is better when attention is focused on the location where the target will appear.

Data was analysed for each ADys case in turn. A significant main effect of flanker was found for all ADys cases ($p < 0.001$), indicating fastest RTs in the neutral condition and slowest RTs in the incongruent-flanker condition (see Table 9.3). The response time of each ADys case was compared with the control group in each flanker condition using Crawford and Howell (1998) modified $t$-test. Case SM showed significantly slower RTs compared to the control group, for both the incongruent-flanker condition (1186 vs 705 msec; $p < 0.01$), and the congruent-flanker condition (928 vs 605 msec; $p < 0.01$). (Case SM also showed lower accuracy, which may indicate a processing difficulty due to the increase in stimuli presented and/or deficient executive control.) Case GM demonstrated significantly slower RTs than the control group for all flanker conditions.

A significant main effect of cue type was also found ($p < 0.05$). As with the control group, for each ADys case the slowest responses occurred in the no-cue condition. In contrast to the control group, the fastest RTs occurred in the double-cue condition as opposed to the spatial-cue condition, indicating better performance when attention is spread in the general area of both possible target locations. Responses in the spatial- and centre-cue conditions are examined in the following section.
Assessing attentional networks

Following the Posner model (Posner and Petersen, 1990), the attentional effects of alerting, orienting and executive control were computed and are presented in Figure 9.5. The alerting effect was calculated by subtracting the mean RT of the double-cue condition from the mean RT of the no-cue condition. The mean alerting effect for the control group was 33 msec with a standard deviation of 11 msec. The orienting effect was calculated by subtracting the mean RT of the valid-cue condition from the mean RT of the centre-cue condition. The mean orienting effect for the control group was 34 msec with a standard deviation of 12 msec. The executive control effect was calculated by subtracting the mean RT of the congruent-flanker condition, summed across cue types, from the mean RT of the incongruent-flanker condition. The mean effect of executive control for the control group was 99 msec with a standard deviation of 36 msec.

A correlational analysis demonstrated no significant correlations between the three forms of attention: alerting, orienting and executive control (largest $r = 0.331, p > 0.05$). This is consistent with previous reports and it has thus been suggested that each attentional effect is functionally independent (e.g., Fan et al., 2002). Comparisons were made between the means of the control group and that of each ADys case for each attentional effect using the Crawford and Howell (1998) modified $t$-test. The alerting effect for all ADys cases was not significantly different to the control group ($p > 0.05$). Thus, the presence of a cue prior to target presentation appears to have increased the level of readiness in both the control group and each ADys case. In contrast, the orienting effect was significantly different to the control group for all ADys cases ($p < 0.05$). Further analysis using single sample $t$-tests revealed that, for all ADys cases, RTs to centre-cue targets were no different to RTs to spatial-cue targets ($p > 0.05$). From this result it appears that the single spatial (valid) cue is not orienting attention to the specific location, since this cue did not result in decreased RT compared to the single centre (invalid) cue.
Figure 9.5: Alerting, orienting and conflict measures of attention for the control group, and the distribution of means for the ADys cases. Those cases that were significantly different to the control group are identified.

Furthermore, RTs to spatial-cue targets were significantly greater than RTs to double-cue targets for all ADys cases ($p < 0.05$). Together with the previous finding of faster RTs in the double-cue than no-cue condition, these findings suggest that although attention may be alerted by a single cue (as indicated by faster RTs when a single cue is presented compared to when no cue is presented), the focus of attention remains more diffuse (encompassing a larger visual area) than when a double-cue is presented for the ADys cases. (Perhaps because the double-cue provides enough stimulation to the attentional system to activate a reduction in focus size.) In regard to executive control, only one case (SM) showed a significantly different effect to the control group, requiring much longer RTs to resolve conflict ($p < 0.001$).

Summary of results

Results for all ADys cases were comparable to those of the control group on two attentional functions, alerting and, with the exception of SM, executive function. In contrast, the control group demonstrated faster target detection when attention was alerted and oriented to the subsequent spatial location.
of the target by a single cue, whereas, for the ADys cases, target detection was fastest when attention had been alerted and oriented by a double cue. Furthermore, the single spatial cue in this experiment did not appear to provide the expected orienting effect on attention for any of the ADys cases. In fact, the single spatial cue resulted in longer RT than for the double-cue presentation.

9.2.3 Discussion

This study of ADys cases showed that while the alerting effects of attention appeared intact, and only two cases, GP and SM, showed a significant deficit in executive control, there were specific orienting difficulties evident for all. These findings are consistent with previous dyslexia research (Facoetti et al., 2000b; Iles et al., 2000; Roach et al., 2004; Vidyasagar and Pammer, 1999) and suggest an impairment of visual attention in these individuals.

The Sluggish Attentional Shifting (SAS) hypothesis of dyslexia proposes that impaired processing of rapid stimulus sequences arises due to sluggish attentional capture (i.e. a deficit in stimulus engagement and disengagement) and prolonged attentional dwell time (Hari and Renvall, 2001). Many studies have reported slower responses by individuals with dyslexia to rapidly presented visual stimuli (e.g., Laasonen, Service, and Virsu, 2002; Tallal, 1980). While the time between cue presentation and subsequent target presentation (Stimulus Onset Asynchrony; SOA) in each of our experiments is close to optimum for the control group (see Cheal and Lyon, 1991; Muller and Rabbitt, 1989; Nakayama and Mackeben, 1989) it may be too short for the ADys cases. It has been reported that the temporal separation necessary for distinguishing two stimuli presented in rapid succession is as much as 100 msec longer for individuals with dyslexia (Lovegrove, 1993). Hari and colleagues (1999) reported the attentional dwell time of a group of adults with dyslexia to be as much as 30% longer than normal readers on an attentional blink task. Indeed, we recently reported longer attentional dwell times for each of the dyslexia
cases also tested in the present study (Buchholz and Aimola Davies, 2007a). If one accepts the SAS hypothesis, then in Experiment 6, this may explain both (a) the absence of attentional costs (engagement deficit) when an invalid peripheral cue (6.5°) is presented either at another peripheral location or more centrally (3°), and (b) the larger attentional costs (disengagement deficit) when a more central invalid cue (3°) is used and the target is presented peripherally (6.5°). However, if a disengagement deficit at 3° were present, it is difficult to fully reconcile the finding that the cases of ADys were able (although slower) to disengage their attentional focus when shifting attention within this location. That is, for an invalid cue at 3° in the upper visual field and target at 3° in the lower visual field, or vice versa. Similarly, it may be argued that, since the discrimination task in Experiment 7 is more difficult than the detection task in Experiment 6, the SOA provided is not long enough to allow time for attention to be engaged. Thus, it is understandable that there is no observable difference between response times for the central-cue condition and the spatial-cue condition. There is no orienting effect because the attentional focus is the same for each condition. What remains difficult to explain, based on this theory, is the finding that there is an advantage of a double-cue for target discrimination. What we wish to argue for here is an alternative account for these results. We propose that, although individuals with dyslexia clearly demonstrate an alerting effect following cueing at all locations in the visual field, they may distribute their attention more widely, so that their attentional focus may not be reduced to the same degree by the cue as it is for controls, and importantly, the resulting deficits are most notable in the periphery.

When viewing a visual display, attention may be allocated evenly across the entire display or can be focused on only one location within the display. Castiello and Umilta (1990) examined the effect on response times of varying target locations relative to cued positions in a group of neurologically normal participants. Response times became progressively faster as targets were placed closer to the cued location. They concluded that the attentional focus
was adjustable. In addition, they examined the effect on RTs of varying both the presentation size of valid cues and SOA. They found that RTs were faster when cue size was smaller. That is, as cue size became smaller, attentional focus size became smaller, allowing attentional resources to become more concentrated within a narrowly defined border and processing speed to become faster at the cued location.

Given that Experiment 6 is a detection task and Experiment 7 is a discrimination task, a direct comparison between measures cannot be made. However, since the underlying process of attentional orienting is measured in both experiments, it is possible to conclude that this process is compromised in dyslexia. Instead of a direct comparison of Experiment 6 and Experiment 7, the characteristics of the attentional orienting difficulties in ADys can be explored by comparing the findings of the present study to previous research using similar methodologies of detection or discrimination. As we will demonstrate, this area of research is limited and therefore comparisons are also confined.

In Experiment 6, it is assumed that faster RTs to validly-cued targets occur because processing in the cued area is facilitated, while slower RTs to invalidly-cued targets occur because, as with the control group, the attentional focus must be disengaged from the cued location and shifted to a new location. Using a cue size of 1° visual angle with the ADys cases, significant orienting difficulties were found only in the periphery (6.5°), as there was normal orienting performance close to fixation (3°). Thus, the 1° cue size was able to facilitate a narrowing of attentional focus close to fixation. In comparison, response time was slower to targets following valid cues in the periphery (since no facilitation occurred), while response time was faster to targets following a peripheral invalid-cue (since no disengagement and shifting of attentional focus from the periphery was required). The overall result is a lack of an effect of orienting in the periphery. A lack of an effect of orienting is similarly indicated by the finding that there is no significant difference in RTs to targets close to fixation following an invalid peripheral cue when compared specifically with valid cues.
in these locations.

The findings of Experiment 6 are consistent with those of Facoetti and colleagues (2000b; 2003), where orienting deficits were observed in the periphery (8° and 10°) for children with dyslexia. It is noted that these researchers used larger cue sizes than in our experiment, that is 1.5° and 2.5° respectively. In support of the hypothesis for a larger (less effective) peripheral focus size in dyslexia, Facoetti and colleagues (2000b) reported that, although children with dyslexia were capable of focusing on cue sizes of 2.5° and 7.5° presented peripherally (10°), they had difficulty maintaining the smaller attentional focus size with longer SOAs (504 msec). These results are relevant to the findings of Experiment 6. The longer RT costs of shifting attention to a peripheral target with an invalid cue close to fixation (see ADys cases GM and TC) may occur because, in addition to the requirement to disengage the attentional focus from the more central cue, the ADys may not be able to maintain the smaller focus size in the periphery.

Our findings are also supported by what at first seems to be contradictory results by Roach and Hogben (2004). They used a cue size less than 0.5° and, in adults with dyslexia, found a decreased orienting effect close to fixation (4°), which contrasts to our findings of effective orienting at 3° from fixation with a 1° cue size. These findings from Experiment 6, along with previous research, demonstrate that individuals with dyslexia may have both a larger attentional focus (in the parafovea and the periphery), and be less effective at maintaining the attentional focus. Furthermore, it appears that the attentional focus size increases with eccentricity. Therefore, in order to detect an orienting deficit in dyslexia, stimulus characteristics such as cue size and SOA need careful consideration.

In Experiment 7, a cue size of 0.5° of visual angle did not appear to facilitate a narrowing of attentional focus size, that is, to the extent that it could assist target discrimination with valid (spatial) cueing, or or result in RT costs when disengaging and shifting the attentional focus with invalid (central) cueing.
These findings are consistent with a discrimination study conducted by Bran-
nan and Williams (1987), which demonstrated an orienting deficit in children
with dyslexia at 2° from fixation. However, it should be noted that while the
cue size was < 0.5°, the SOA was much shorter than that used in Experiment
7. The detection task used by Bednarek and colleagues (2004) may be more
directly comparable to that used in Experiment 7 with the only major method-
ological difference being a larger cue size (> 0.5°). These researchers found
no significant differences in alerting and orienting performance between their
dyslexia and control groups. However, they report poorer performance for their
dyslexia group on executive control. They suggest that their findings indicate
a disability in narrowing the focus of attention and in inhibiting interference.
There are two immediate explanations for the lack of an executive attention
effect in this study. Individuals with dyslexia may have a developmental delay
in the maturation of their executive system. As children, they would show a
deficit in executive control (as in Bednarek et al., 2004) which would disappear
as they grew older and gained more experience (as in this study). Another pos-
sibility could reflect the difference in participant samples in the two studies.
For example, difficulties in executive function are an important component of
attention deficit disorders (ADD/ADHD) (Roth and Saykin, 2004; Sergeant,
Geurts, and Oosterlaan, 2002; Willcutt, Doyle, Nigg, Faraone, and Pennington,
2003), and a high rate of comorbidity of ADD/ADHD and dyslexia (20 - 40%)
has been reported in children (Willcutt and Pennington, 2000). In this study,
participants did not demonstrate, nor had a history of, an attentional deficit
disorder (ADD or ADHD). No screening for such was reported by Bednarek
and colleagues (2004): therefore, their results of an executive function deficit
may reflect the presence of ADD/ADHD in their participants. This hypothe-
sis suggests that the underlying attentional difficulties are different for the two
disorders (see also Pennington, Grossier, and Welsh, 1993). Further research
is required in this area.

The double-cue to single-cue advantage, demonstrated by the individuals
with dyslexia in Experiment 7, suggests that the two points of reference in the double-cue condition provided a means for reducing the attentional focus at least to that extent, in comparison to no benefits with the single cue. It is proposed that this difficulty with the single-cue may be a difficulty specific to reducing the attentional focus size. This may explain previous findings that suggest a diffuse attentional system, that is, the system has difficulty in reducing focus under conditions where a control group has no difficulty. Putting together the results from Experiment 7 and those from the study by Bednarek and colleagues (2004), it appears that the attentional focus at fovea is also larger in dyslexia.

The comparisons of the detection and discrimination tasks used in this study to those of previous researchers (Bednarek et al., 2004; Brannan and Williams, 1987; Facoetti et al., 2000a; Roach et al., 2004) suggests that the size of the attentional focus varies across the visual field. That is, the size that the attentional focus can be reduced to, and maintained at, is affected by spatial location. However, the various studies described have methodological differences, such as detection versus discrimination, cue size, SOA, presentation in the vertical versus horizontal meridian and child versus adult participants, which necessitates caution in this interpretation. More robust support for this interpretation will require a systematic investigation of the effects of cue size, SOA, and cue position on orienting ability in individuals with dyslexia (Buchholz and Aimola Davies, 2007b,c).

Visual attention is a major contributor to the development of competent reading. For example, evidence suggests that sustained focused attention is required for the analysis of strings of letters or words during fixations (LaBerge and Brown, 1989), in addition to fast and accurate control of saccades between fixations (Inhoff et al., 1989). Allocating attention to useful information that will facilitate processing at subsequent fixations, or parafoveal preview benefit (Rayner et al., 1989), also requires that irrelevant or conflicting information be ignored. The size of the region from which useful information is
obtained during an eye fixation is referred to as the perceptual span (McKonkie and Rayner, 1975). Several studies have shown that this span may vary according to the difficulty a reader has in processing foveal information (Henderson and Ferreira, 1990; Inhoff et al., 1989; Schroyens et al., 1999) and in deciding the relevance of parafoveal information (Bertera and Rayner, 2000; Rayner and Fisher, 1987). Several studies have also demonstrated that individuals with dyslexia have difficulty suppressing peripheral information which could interfere with foveal processing (Geiger et al., 1994; Geiger and Lettvin, 1999; Rayner et al., 1989). Thus, fluent reading requires processing of a fixated word together with information from the next word in the text (Rayner, 1998). The difficulties with orienting attention in the periphery (all ADys cases), as demonstrated in Experiment 6 of this study suggest that, when reading, individuals with dyslexia are less able to readily gather information from words that are not currently fixated. This lack of parafoveal preview benefit leads to a slowed reading speed by these individuals. In addition to slowed processing, these difficulties would interfere with the sequential left-to-right scanning that is characteristic of phonological coding and necessary for reading fluently. That is, it would be more difficult to make the visual/verbal correspondences required to learn the phonological representations of new words and integrate them into memory. Finally, reducing attentional focus size allows distracting information to be minimized during reading, and therefore local word information (letters) can be processed quickly and accurately. If the size to which the attentional focus can be reduced is both limited and dependent on location in space, then, the slowed processing of visual information and the greater confusion across words often reported in individuals with dyslexia (Stein, 1991) is more clearly explained.

**Concluding remarks**

Taken together, the results of this study indicate that the attentional deficit in dyslexia may be specific to orienting. It is suggested that the ability to adjust
and maintain the size of the attentional focus is both deficient and limited
in individuals with dyslexia, with these difficulties exacerbated in peripheral
spatial locations. These deficits may account for the slowed reading and slowed
visual processing observed in studies of dyslexia.
Chapter 10

Characterising the attentional orienting deficits observed in adults with dyslexia

The ability to covertly orient attention, that is, orienting without eye movements, is typically investigated using spatial cueing experiments (Posner, 1980). The general method requires presentation of a spatial cue followed by a target, either in the same position as the cue (valid) or in an alternate location to the cue (invalid). The type-of-cue effect is shown when response times in the valid-cue condition are faster than in the invalid-cue condition. This difference in response time for the two conditions provides a measure of orienting ability. An additional condition may be included where both possible positions for the target are cued (neutral), or where no cueing occurs before target presentation (no-cue). The difference between the neutral and valid-cue conditions provides a measure of the benefit of valid cueing, and the difference between neutral and invalid-cue conditions provides a measure of the cost of invalid cueing. Comparisons of response times of the cued conditions to the no-cue condition indicate the ability to detect and respond to a cue. Response times are re-
quired to be faster for both valid- and invalid-cued conditions compared with the no-cue condition.

On spatial cueing tasks, individuals with dyslexia have generally been reported to respond more slowly to targets than individuals without dyslexia. In addition, individuals with dyslexia have demonstrated benefit from the use of cues. For example, Brannan and Williams (1987) found that, unlike children who were good readers, children who were poor readers did not demonstrate improved accuracy for identification of target letters in the parafovea (2° from fixation) with cueing. Similarly, adults with dyslexia have shown a lack of (attentional) facilitation in performance with cueing in a search task where the array was presented at locations 5° from fixation (Roach, Edwards, and Hogben, 2004). Also, in a study by Facoetti et al. (2000b), there was no effect of valid peripheral cues (10° from fixation) on performance observed for children with dyslexia. The reduced sensitivity to cueing of the groups with dyslexia suggest that the cues were not efficient at stimulating attentional processes.

An inability to benefit from cues has not always been reported. For example, Buchholz and Aimola Davies (2005) (see Chapter 6) found that adults with dyslexia showed performance benefits of valid cueing in the parafovea (3° from fixation), but reduced benefits were observed in the periphery (6.5° from fixation). In another study, Buchholz and Aimola Davies (2007a) (see Chapter 9) found that this same group of adults with dyslexia showed no benefits of valid cueing in the fovea (1° from fixation). In contrast, Bednarek, Saldana, Quintero-Galleco, Garcia, Grabowska, and Gomez (2004) found children with dyslexia did demonstrate performance benefits for a valid cue at this location.

It is proposed that these seemingly contradictory findings for benefits from cueing may relate to differences in methodology, such as stimulus characteristics: cue size, time between cue onset and target onset (stimulus onset asynchrony, SOA) and visual field of presentation. Any or all of these factors may differentially affect the attentional ability of individuals with dyslexia compared to good readers.
Manipulating these variables in spatial cueing tasks may allow the limitations of attention to be examined. For example, the effects of stimulus location on the allocation of attention can be examined by varying eccentricity and visual field of presentation. Limitations in the size the attentional focus can be adjusted to may be determined by varying cue size, while the ability to maintain attentional focus can be examined by varying SOA.

Many studies have demonstrated that the performance of normal readers drops when stimuli of fixed size are presented at greater eccentricities (see Golla, Ignashchenkova, Haarmeier, and Thier, 2004; Levi, McGraw, and Klein, 2000; Yeshurun and Carrasco, 1999). These findings are indicative of the loss of spatial resolution (visual acuity) as stimuli are presented further in the retinal periphery. Spatial cues have been shown to improve performance both at peripheral locations (Carrasco, Williams, and Yeshurun, 2002; Yeshurun and Carrasco, 1998) and locations closer to fixation (Carrasco, Giordano, and McElree, 2006). In addition, Golla et al. (2004) have reported benefits of cueing at retinal eccentricities ranging between 3° and 15°, with greater benefits as eccentricity increased and fewer benefits at longer SOAs. Several cueing studies of children with dyslexia, by Facoetti and colleagues (Facoetti, Lorusso, Paganoni, Cattaneo, Galli, Umilta, and Mascetti, 2003; Facoetti and Molteni, 2001; Facoetti, Paganoni, and Lorusso, 2000a; Facoetti, Paganoni, Turatto, Marzola, and Mascetti, 2000b), have shown that the performance of these children does not change when eccentricity is increased from central fixation. Specifically, the overall response times were slower than a comparable control group, and no difference in response times was observed between valid and neutral cueing conditions. The researchers proposed that this orienting difficulty (i.e., difficulty in narrowing attentional focus) is the result of a diffusely distributed attentional system.

The poorer performance shown by individuals with dyslexia on spatial cueing tasks may relate to a difference in spatial acuity (Evans, Drasdo, and Richards, 1994) rather than attentional mechanisms. It has been demon-
strated, in individuals without dyslexia, that performance at a fixed eccentricity improves when cue size decreases (see Castiello and Umilta, 1990; Turatto, Benso, Facoetti, Galfano, Mascetti, and Umilta, 2000). As focus size gets smaller, attentional resources become more concentrated within its border and processing speed becomes faster. Thus, the generally slower response times often reported in individuals with dyslexia may be a consequence of using a larger focus size. Such a visual deficit in dyslexia is further suggested by findings and observations of decreased reading performance by individuals with dyslexia when reading small print (Cornelissen, Bradley, Fowler, and Stein, 1991; Skottun, 2001). However, Facoetti et al. (2000b) reported that children with dyslexia demonstrated a cue size effect (that is, better performance with the smaller 2.5° cue size compared to the 7.5° cue size) comparable to controls at short SOA (99 msec), therefore demonstrating that they were able to reduce attentional focus. When SOA was increased (504 msec), although these same individuals showed improved performance in both cue size conditions, a cue size difference was no longer evident. In contrast, the control group demonstrated an improvement in performance for both cue sizes (see Castiello and Umilta, 1990; Turatto, Benso, Facoetti, Galfano, Mascetti, and Umilta, 2000), while maintaining better performance with a smaller cue. These results suggest that individuals with dyslexia have difficulty maintaining attentional focus, and shift to a more distributed modality of attention, resulting in poorer relative performance with the smaller cue.

Temporal processing can be broadly defined to include any type of processing required when two or more stimuli are presented in sequence. Tallal (1984) has proposed that the phonemic deficit often seen in dyslexia is a symptom of a more general deficit in processing rapid temporal sequences. Deficits in temporal processing have been extensively reported in both adults and children with dyslexia (Ben-Artzi, Fostick, and Babkoff, 2005; Eden, VanMeter, Rumsey, and Zeffiro, 1996b; Galaburda, 1993; Kinsbourne, Rufo, Gamzu, Palmer, and Berliner, 1991; Laasonen, Tomma-Halme, Lahti-Nuuttila, Service, and Virsu,
Hari, Valta, and Uutela (1999) have proposed that the temporal deficits observed in dyslexia are secondary to a more fundamental attention deficit, specifically a sluggish attentional system. Their attentional system is considered to be slower at directing attention to each successive stimulus, and/or less able to maintain attention on each stimulus for the time required to allow processing and identification to be completed.

Carrasco, Talgar, and Cameron (2001) have examined the visual factors underlying spatial performance fields. They reported that performance in normal readers is best along the horizontal meridian (left and right) of the visual field, followed by the vertical meridian (upper and lower). In addition, within the vertical meridian, performance is worse in the upper compared to the lower location (vertical meridian asymmetry, VMA). Talgar and Carrasco (2002) demonstrated that these visual field asymmetries are a function of visual perceptual differences rather than covert attention constraints by presenting cues across locations. No change in performance asymmetry was observed (i.e., cueing improved performance uniformly across locations), thus indicating covert attention was not a determining factor for the observed performance asymmetries.

Studies investigating attentional performance along the horizontal meridian in children with dyslexia have reported an asymmetry in cueing effects between the left and right visual fields (Facoetti and Turatto, 2000; Facoetti, Turatto, Lorusso, and Mascetti, 2001). These findings have suggested to the authors that one characteristic of dyslexia may be difficulties with left visual field inattention and right visual field over-distractibility. Other researchers have reported a “left mini-neglect” in both adults (Hari and Renvall, 2001) and children (Sireteanu et al., 2005) with dyslexia.
The present research

This study aims to extend research examining attentional abilities of adults with dyslexia. In this set of experiments, stimulus characteristics (such as cue type and size, SOA, visual field, eccentricity) are manipulated within spatial cueing tasks to examine the effect of these changes on performance. No study has previously examined all of these variables in one sample of adults with dyslexia.

Experiment 8 examines the ability of individuals with dyslexia to benefit from cueing at various eccentricities, along both the horizontal and vertical meridians. Target detection is assessed both with and without a cue. Once the benefits of cueing are established and specified, cue size and SOA are manipulated systematically in Experiment 9. Thus, the ability both to reduce and maintain attentional focus are examined. Experiment 10 involves the inclusion of an invalid-cue condition (extending on Experiment 9) which also examines the ability to shift attentional focus.

10.1 Experiment 8

This first spatial cueing experiment examines three aspects of stimulus presentation on target detection. Specifically, the ability to detect a 0.5° target, with or without a 1.0° spatial cue, is examined in a group of adults with dyslexia and a group without. Three eccentricities from fixation are used, along each of the horizontal and vertical meridians.

10.1.1 Method

Participants

Five ADys cases from the experimental pool: GP, SM, SW, GM and TC participated in this experiment (cases TM, RM and JM were unavailable).
The control group consisted of 16 adults with no history of reading difficulties. For psychometric assessment results see Chapter 3.

**Apparatus**

Stimuli were presented using Psyscope software on an Apple Macintosh computer running OS-9 with a 17-inch computer screen and a refresh rate of 85 Hz. The viewing distance was set to 50 cm using a chin rest.

*Eye monitoring:* Eye fixation in dyslexics has been shown to be unsteady when attempting to view small letters, and pursuit eye movements have been shown to be less smooth than in normal readers (Eden, Stein, Wood, and Wood, 1994; Griffen, Christenson, Wesson, and Erickson, 1998; Stein, Riddell, and Fowler, 1988). One might expect that this unstable vision would lead to visual confusion and thus reading errors. Indeed, many individuals with dyslexia complain of letters and words moving around, merging and crossing over (Cornelissen, Bradley, Fowler, and Stein, 1991). However it seems unlikely, given the frequent co-existence of visual problems with language and sequencing deficits, that defective eye movements would be the direct cause of dyslexia.

Never-the-less, covert deployment of attention may be examined through several methods such as, employing stimuli too brief to allow eye movements (e.g., Vecera, 1994)), requiring participants to hold a steady focus during stimulus presentation (e.g., Abrams and Law, 2000), presenting stimuli at fixation (e.g., Kramer, Weber, and Watson, 1997), and using methods not expected to produce differential eye-movement effects (e.g., Yantis, 1992).

The previous experiments in this research were conducted such that stimulus presentation times were short, and procedures required participants to focus on a fixation cross during stimulus presentation. For this set of experiments, eye movements were monitored using *Eye Monitoring Equipment*
(Model 6500, Class B. Made by: R & R Mechanatronics: HOORN, Holland) and a IBM computer, connected to the Apple computer via a button box. Trials were repeated if they contained an eye movement greater than 1° of visual angle (VA; see Figure 10.1).

![Figure 10.1: Eye Monitoring Equipment: Model 6500, Class B. Made by: R & R Mechanatronics: HOORN, Holland.](image)

**Procedure**

A new spatial cueing task was designed to examine the ability of both ADys and control participants to detect a target, with and without cueing, at various eccentricities along both the horizontal and vertical meridians. The cue consisted of an open (white with black outline) circle of 1.0° VA and the target was a closed (black) circle of 0.5° VA. A fixation cross, 0.4° × 0.4° VA was presented at the centre of the screen throughout each trial. After 300 msec the cue appeared for 100 msec, followed immediately by the target, such that the SOA was 100 msec. Stimulus characteristics varied as follows: (i) eccentricity of stimulus presentation (1°, 3° and 7° VA from fixation), (ii) spatial performance field (hereafter referred to as visual field) of stimulus presentation (left of fixation = LVF, right of fixation = RVF, above fixation = AVF and below fixation = BVF), and (iii) cue validity (valid or no-cue condition).
There were 5 blocks of trials with 144 trials per block. Trials were divided into: 10% catch trials (cue without a target), 80% valid (cue and target in same location) and 10% no-cue (target without a cue). All stimulus conditions were presented randomly in each block. An example of the procedure is presented in Figure 10.2.

Figure 10.2: An example of the valid-cue procedure for stimuli presented on the right of fixation (cue and target appear at same location). Broken circles represent the two other possible locations for stimuli presentation.

Participants were instructed to maintain fixation on the fixation cross throughout the experiment, and encouraged to rest between blocks. The task was to press the “m” key on the keyboard as quickly as possible when they detected the presence of the target. Each trial ended once a response had occurred, or after 1200 msec.

10.1.2 Results

Response times (RTs) less than 100 msec were excluded as anticipations, and trials where timeouts occurred were also excluded from analysis. No participant responded to more than 5% of catch trials. The total amount of data removed in the screening process was approximately 2%.

Mean RTs were analysed with a repeated measures Analysis of Variance (RM-ANOVA) where the within-subjects factors were cue type (valid-cue, no-cue), eccentricity (1°, 3°, 7°) and visual field (LVF, RVF, AVF, BVF). The between-subjects factor was group (control, ADys). The overall mean RT
for the ADys group (441 msec) was not significantly slower than the control group (410 msec; $F(1,19) = 1.9, p > 0.15$). The main effect of visual field was significant, $F(3,57) = 7.1, p < 0.001$. Planned contrasts revealed no significant difference between RTs in the LVF (429 msec), RVF (426 msec) and BVF (432 msec), but significantly slower RTs in the AVF compared to the other visual fields (443 msec; $F(1,19) = 19.9, p < 0.001$).

There were significant effects of cue type ($F(1,19) = 44.1, p < 0.001$) and eccentricity ($F(2,38) = 8.3, p < 0.001$), as well as a significant interaction of these factors ($F(2,38) = 3.5, p < 0.05$). There was also a significant 3-way cue type×eccentricity×group interaction ($F(2,38) = 3.6, p < 0.05$), which is plotted in Figure 10.3.

![Figure 10.3: Response times for the control and ADys groups as a function of eccentricity for each cue condition. Vertical bars represent SEM.](image)

In order to further examine the nature of the cue type×eccentricity×group interaction, each cue type (valid-cue, no-cue) condition was analysed separately. For the no-cue condition a significant main effect of eccentricity ($F(1,19) = 5.8, p < 0.05$) indicated that the pattern was the same for both groups, with RTs being generally shorter at $1^\circ$ eccentricity (454 msec) followed by those at $3^\circ$ eccentricity (460 msec), and longest at $7^\circ$ eccentricity.
(472 msec). For the valid-cue condition, a significant eccentricity \( \times \) group interaction was shown \((F(1,19) = 8.9, p < 0.01)\). Single sample \( t \)-tests on RT difference between 3° eccentricity and each of the other eccentricities were carried out for each participant group separately. Of note, there were significantly faster RTs as eccentricity increased from 1° to 3° for the ADys group (25 msec, \( t(4) = 7.3, p < 0.01 \)), but no significant change for the control group (4 msec, \( t(15) = 1.3, p < 0.2 \)). The results also indicated significantly slower RTs as eccentricity increased from 3° to 7° for both the ADys group (19 msec, \( t(4) = 3.4, p < 0.05 \)), and the control group (9 msec, \( t(15) = 2.6, p < 0.05 \)).

In the conditions that showed significant group differences comparisons were made between the ADys cases to control group, using the modified \( t \)-test with \( \alpha = 0.01 \). There was a trend for RTs of the ADys cases to be slower than the control group, but only case GM clearly demonstrated significantly slower RTs. All ADys cases showed reduced RTs as eccentricity increased from 1° to 3° eccentricity in the valid-cue condition, and this was significantly larger than that shown by the control group for all except case GM.

10.1.3 Discussion

Experiment 8 examined the participants’ ability to benefit from a cue (indicating correct target location) at three eccentricities from fixation, along each of the horizontal and vertical meridians.

As expected, the control group demonstrated benefits of cueing at all eccentricities, that is, faster responses were given to a target when a valid-cue was given compared to responses when there was no cue. This is consistent with previous spatial cueing experiments (Egly et al., 1994a; Posner, 1980). The adults with dyslexia also showed benefits of cueing which were comparable to the control group. This finding is consistent with our previous research where I have examined cueing effects of a 1° cue at eccentricities of 3° and 7° (Buchholz and Aimola Davies, 2005, 2006, 2007a, see Chapters 6, 8, 9).
With respect to expected eccentricity effects (as indicated by slower RTs with increasing eccentricity), the findings provide some support for previous research (e.g., Golla et al., 2004; Levi et al., 2000; Yeshurun and Carrasco, 1999). The control group showed the expected effect between 3° and 7°, but no change in performance was observed between 1° and 3°. The expected effect was also observed for the ADys group (and all individual ADys cases) between 3° and 7°. However, although the control group had shown no RT difference between 1° and 3°, the ADys group demonstrated faster RTs at 3° than at 1° eccentricity.

One possible explanation for these findings may relate to previous findings that, in general for any participant, attentional focus is not sharply demarked, but rather drops-off gradually (Castiello and Umilta, 1990). Therefore, interference from the fixation cross (which was 0.3° from the 1° cue boundary at 1° eccentricity) may have occurred, resulting in poorer responses for both groups close to fixation. Additionally, this finding may reflect a larger attentional focus for the ADys group. Thus, the fixation cross may not just interfere with processing at 1° (as for the control group), but may undergo extra processing as it falls within a larger attentional focus for the ADys group. This would explain the significant eccentricity effect observed for this group.

The findings from the stimulus characteristic of visual field demonstrated that cueing operates similarly for the two groups across the horizontal and vertical meridians. Consistent with previous reports of non-homogeneous performance across visual fields (Carrasco et al., 2001; Talgar and Carrasco, 2002), the performance of both groups was generally best along the horizontal meridian. In the vertical meridian performance in the upper visual field was poorer than the lower visual field. Thus, it appears that these constraints are similar for the two groups.

From Experiment 8, it has been observed that the performance of the ADys group improved with valid cueing. Thus, it appears that a 1° cue can reduce the attentional focus of the dyslexia group to improve target detection, if the
target is presented within 100 msec of the cue at 1°, 3° and 7° eccentricities in each visual field. However, the findings, that performance was better at 3° compared to 1° eccentricity, suggest that the focus of attention in these individuals is more diffuse than that of the control group.

10.2 Experiment 9

Previous studies have also reported a more diffuse attentional focus in individuals with dyslexia. However, in contrast to Experiment 8, findings report an additional problem with ability to use a cue (Brannan and Williams, 1987; Facoetti et al., 2000b; Roach et al., 2004). These studies differed from Experiment 8 in the stimulus characteristics of cue size and SOA. Experiment 9 examines and compares the effects these two stimulus characteristics. Specifically, the ability to detect a 0.5° target following a spatial cue varying in size (0.5°, 1.0°, 3.0°). As with Experiment 8, three eccentricities from fixation are used, along the horizontal and vertical meridians, but with the added manipulation of a varying SOA (100 msec or 400 msec). This manipulation may make it possible to determine whether the individuals with dyslexia (compared with the individuals without dyslexia) require more (or less) time to adjust their attentional focus. Additionally, manipulating the cue size will also allow examination of the size of the attentional focus.

10.2.1 Method

Participants

Participants were the same as in Experiment 8.

Apparatus and procedure

Apparatus was the same as in Experiment 8.
Chapter 10: Characterising the attentional deficits

A fixation cross, $0.4^\circ \times 0.4^\circ$ VA was presented at the centre of the screen throughout each trial. After 300 msec, the cue (open circle) appeared for 100 msec then, after an interval the target (closed circle) appeared. Stimulus characteristics varied as follows: (i) cue size ($0.5^\circ$, $1.0^\circ$ and $3.0^\circ$ VA), (ii) time of SOA (100 msec or 400 msec), (iii) eccentricity of stimulus presentation ($1^\circ$, $3^\circ$, $7^\circ$ VA from fixation), and (iv) visual field of stimulus presentation (LVF, RVF, AVF and BVF). Note that the $3^\circ$ cue was only presented at $3^\circ$ and $7^\circ$ eccentricities to ensure that the fixation cross was not covered.

The experiment was conducted over 3 sessions, each separated by a 30 minute break. Each session contained 5 blocks of trials, each testing a single cue size. There were 232 trials per block: 200 valid trials (50% with SOA of 100 msec and 50% with SOA of 400 msec) and 32 catch trials (cue without a target). Each SOA condition was presented randomly in each block. Each participant was tested first with the $0.5^\circ$ cue, followed by the $1^\circ$ cue and the $3^\circ$ cue.

Participants were instructed to maintain fixation on the fixation cross throughout the experiment, and encouraged to rest between blocks. The task was to press the “m” key on the keyboard as quickly as possible when they detected the presence of the target. Each trial ended once a response had occurred, or after 1200 msec.

10.2.2 Results

Response times (RTs) less than 100 msec were excluded as anticipations, and trials where timeouts occurred were also excluded from analysis. No participant responded to more than 5% of catch trials. The total amount of data removed in the screening process was approximately 2%. 
Eccentricities of 1° and 3°

Mean RTs, for the 1° and 3° eccentricities only, were analysed with a RM-ANOVA where the within-subjects factors were cue size (0.5°, 1°), SOA (100 msec, 400 msec), eccentricity (1°, 3°) and visual field (LVF, RVF, AVF, BVF). The between-subjects factor was group (control, ADys). The overall mean RT for the ADys group (371 msec) was not significantly slower than the control group (351 msec; $F(1, 19) = 0.93$, $p > 0.30$). There was a significant main effect of SOA ($F(1, 19) = 62.9$, $p < 0.001$), as well as significant interactions for SOA×eccentricity ($F(1, 19) = 18.5$, $p < 0.001$), SOA×group ($F(1, 19) = 5.5$, $p < 0.05$) and SOA×eccentricity×visual field×group ($F(3, 57) = 5.8$, $p < 0.01$). These data are presented in Figure 10.4. As can be seen, RTs generally improved with increasing SOA, except at 3° eccentricity in the AVF for the ADys group.

Figure 10.4: Response times for the control and ADys groups as a function of eccentricity and visual field for each stimulus onset asynchrony condition. Vertical bars represent SEM.
SOA × eccentricity × visual field × group interaction: In order to further examine the SOA × eccentricity × visual field × group interaction, data were analysed separately for each visual field. A significant main effect of SOA was found in the BVF ($F(1, 19) = 35.4, p < 0.001$), indicating that both groups showed the same degree of improvement at the longer SOA. An SOA × group interaction was shown in the LVF ($F(1, 19) = 7.1, p < 0.05$) and RVF ($F(1, 19) = 6.2, p < 0.05$). Response times of both groups were faster at the longer SOA. Independent sample t-tests, comparing the two groups, indicated that in each visual field at the longer SOA, the degree of improvement was greater for the control group than for the ADys group; a 26 msec greater improvement in the LVF ($t(19) = 2.7, p < 0.05$) and a 30 msec greater improvement in the RVF ($t(19) = 2.5, p < 0.05$). In the AVF, a significant SOA × eccentricity × group interaction was shown ($F(1, 19) = 12.1, p < 0.01$). Independent sample t-tests comparing the two groups at each eccentricity indicated that the degree of improved performance with longer SOA was 59 msec greater for the control group than the ADys group at 3° eccentricity ($t(19) = 3.9, p < 0.01$).

ADys case-to-control group comparisons were made on conditions having shown significant group differences using the modified t-test with $\alpha = 0.01$. In the LVF, RVF and at 3° eccentricity in the AVF, there was a trend for all ADys cases to show reduced benefits at longer SOA than the control group. However, these differences only reached significance for cases SM, SW, GP and TC at 3° eccentricity in the AVF. (For case TC this occurred because he/she generally responded faster when SOA was shorter).

Eccentricity × cue size × group interaction: Interactions for eccentricity × cue size ($F(1, 19) = 18.8, p < 0.001$) and eccentricity × cue size × group ($F(1, 19) = 10.1, p < 0.01$) were also observed. Data are presented in Figure 10.5. To further investigate the eccentricity × cue size × group interaction, data were analysed separately for each group. There were no significant effects for the control group indicating consistent performance across eccentricity and cue size. A
significant interaction for eccentricity×cue size was found for the ADys group ($F(1, 4) = 10.0, p < 0.05$). Follow-up paired sample $t$-tests revealed distinct cue size differences in performance. Slower RTs were observed with the larger cue size of 1° compared with 0.5° at 1° eccentricity (21 msec, $t(4) = 5.4$, $p < 0.01$), but not at 3° eccentricity (1 msec, $t(4) = 0.002$, $p > 0.95$). Also, with the 1° cue condition, a significant increase in RT was observed at 1° compared with 3° eccentricity (12 msec, $t(4) = 4.3$, $p < 0.01$), but there was no significant change for the 0.5° cue condition (8 msec, $t(4) = 1.5$, $p > 0.20$).

Figure 10.5: Response times for the control and ADys groups as a function of eccentricity for each cue size. Vertical bars represent SEM.

ADys case-to-control group comparisons were made on conditions having shown significant group differences using the modified $t$-test with $\alpha = 0.01$. While there was a trend for RTs of the ADys cases to be slower than the control group, only case GM demonstrated significantly slower RTs in all conditions. All ADys cases tended to have slower RTs with the larger cue size at 1° eccentricity, however, this pattern was not significantly different to the control group for any individual case. This appears due to the greater variability shown by the control group ($s.d. = 21$ msec). The pattern of shorter RTs for the 1° cue size with increased eccentricity (present for all ADys cases) was only significantly different to the control group for cases SM and GP.
SOA×cue size×visual field interaction: An SOA×cue size×visual field interaction ($F(3,57) = 8.6$, $p < 0.001$) was also determined. To further investigate this interaction separate analyses were carried out for each visual field. A significant main effect of SOA was found in the LVF ($F(1,20) = 120.1$, $p < 0.001$), RVF ($F(1,20) = 64.6$, $p < 0.001$) and BVF ($F(1,20) = 58.2$, $p < 0.001$), indicating faster RTs with longer SOA. In the AVF, a significant SOA×cue size interaction was found ($F(1,20) = 6.6$, $p < 0.05$). Paired sample $t$-tests indicated a greater reduction in RT, with longer SOA, only for the 1° cue (by 12 msec, $t(20) = 1.9$, $p < 0.05$).

Eccentricities of 3° and 7°

Mean RTs for the 3° and 7° eccentricities only were analysed with a RM-ANOVA, where the within-subjects factors were cue size (0.5°, 1°, 3°), SOA (100 msec, 400 msec), eccentricity (3°, 7°) and visual field (LVF, RVF, AVF, BVF). The between-subjects factor was group (control, dyslexia). The overall mean RT for the ADys group (376 msec) was not significantly slower than the control group (356 msec; $F(1,19) = 1.3$, $p > 0.25$). There were significant main effects of SOA ($F(1,19) = 52.4$, $p < 0.001$), eccentricity ($F(1,19) = 57.4$, $p < 0.001$) and visual field ($F(3,57) = 4.7$, $p < 0.01$). In addition, there were also significant interactions for SOA×group ($F(1,19) = 5.2$, $p < 0.05$) and eccentricity×group ($F(1,19) = 6.7$, $p < 0.05$). However, these findings should be interpreted in light of the significant SOA×eccentricity×visual field×group interaction ($F(3,57) = 3.5$, $p < 0.05$). Data are presented in Figure 10.6. As can be seen, RTs generally improved with increasing SOA, but tended to be slower in the AVF.

SOA×eccentricity×visual field×group interaction: To further investigate the SOA×eccentricity×visual field×group interaction, data were analysed separately for each visual field. A significant main effect of SOA was found in
the LVF ($F(1,19) = 39.7, p < 0.001$) and BVF ($F(1,19) = 27.8, p < 0.001$), indicating that both groups showed the same degree of improvement in performance at the longer SOA. A significant main effect of eccentricity was also found in the BVF ($F(1,19) = 11.8, p < 0.01$), indicating overall faster RTs at $3^\circ$ eccentricity for both groups. In the AVF, a significant SOA×eccentricity×group interaction was shown $F(1,19) = 12.1, p < 0.01$. Independent sample $t$-tests comparing the groups at each eccentricity indicated that improved performance with longer SOA was greater for the control group than the ADys group at $3^\circ$ eccentricity (by 46 msec, $t(19) = 3.6, p < 0.01$). In the RVF, there were significant interactions for SOA×group ($F(1,19) = 7.1, p < 0.05$) and eccentricity×group ($F(1,19) = 8.1, p < 0.05$). Response times of both groups were faster at the longer SOA and faster at $3^\circ$ eccentricity, respectively. Independent sample $t$-tests comparing the two groups, indicated
that improved performance with longer SOA was greater for the control group than the ADys group (by 25 msec, \( t(19) = 2.1, p = 0.05 \)), but at 3° eccentricity was greater for the dyslexia group than the control group (by 14 msec, \( t(19) = 2.8, p < 0.05 \)).

ADys case-to-control group comparisons were made on conditions having show significant group differences using the modified \( t \)-test with \( \alpha = 0.01 \). In the RVF, there was a trend for all ADys cases (except case GM) to show reduced benefits of longer SOA than the control group, and in the AVF, this was evident for all ADys cases at 3° eccentricity. However, these differences only reached significance for cases TC and SW in the RVF, and cases SM, GP and TC at 3° eccentricity in the AVF. Case TC also tended to respond faster when SOA was shorter.

\( \text{SOA} \times \text{cue size} \times \text{visual field interaction} \): There was a significant main effect of cue size \( (F(2,38) = 4.8, p < 0.05) \), and a significant SOA×cue size×visual field interaction \( (F(6,114) = 2.7, p < 0.01) \). To further investigate this interaction, separate analyses were carried out for each visual field. A significant main effect of SOA was found in the RVF \( (F(1,20) = 72.9, p < 0.001) \), AVF \( (F(1,20) = 90.3, p < 0.001) \) and BVF \( (F(1,20) = 47.8, p < 0.001) \), indicating faster response times with longer SOA. In the LVF, a significant SOA×cue size interaction was found \( (F(1,20) = 7.2, p < 0.01) \). Paired sample \( t \)-tests revealed a significantly greater reduction in RT as SOA increased only for the 0.5° cue compared to the 1° cue (by 15 msec, \( t(20) = 3.0, p < 0.01 \)) and the 3° cue (by 20 msec, \( t(20) = 3.3, p < 0.01 \)).

### 10.2.3 Discussion

The aim of this experiment was to examine the effects of manipulating both cue size and time between cue and target onset (SOA) on target detection, and to compare these effects for a group of adults without dyslexia with those
of a group with dyslexia.

The usual cue size effect, as indicated by slower RTs with increasing cue size (e.g., Castiello and Umilta, 1990; Turatto et al., 2000), was not observed in this experiment for either the control group or the dyslexia group. Overall, there was no RT difference between the 0.5° cue and the 1° cue, and the RTs for the 3° cue were shorter. One possible explanation for this unusual finding may be that a practice effect occurred since each cue size was presented in separate blocks of trials, beginning with the 0.5° cue followed by the 1° cue, and finishing with the 3° cue. Improved performance across blocks may have masked any cue size effect, and account for the observed improvement with the largest cue size.

The usual SOA effect, as indicated by shorter RTs with increasing SOA (see Castiello and Umilta, 1990; Turatto et al., 2000), was observed for both the control group and the group with dyslexia. However, the results of this experiment indicate a tendency for the dyslexia group (particularly case TC) to show less benefit of longer SOAs than the control group. This finding may indicate a reduced ability to maintain attentional focus at longer SOAs as has been previously reported in children with dyslexia (Facoetti et al., 2000b).

The usual eccentricity effect, as indicated by slower RTs with increasing eccentricity (e.g., Golla et al., 2004; Levi et al., 2000; Yeshurun and Carrasco, 1999) was observed for both groups with the 0.5° cue. For the 1° and 3° cue sizes, this eccentricity effect only occurred between the 3° and 7° eccentricities. These effects tended to be greater for all cases with dyslexia, suggesting increasing difficulty in focusing attention further from fixation. As in Experiment 8, the control group showed a lack of an eccentricity effect between the 1° and 3° eccentricities with the 1° cue, and the group with dyslexia demonstrated faster RTs with increasing eccentricity for this cue size.

Finally, visual field differences were again observed for both groups with performance most varied along the horizontal meridian and poorest in the
upper visual field. In addition, visual field differences between the two groups were also observed, with the ADys group generally demonstrating less benefit of a longer SOA at all eccentricities in the RVF, and at 3° eccentricity in the AVF. However, this does not appear to be a consistent difficulty in dyslexia, as for example, case GM did not demonstrate difficulties in any visual field.

10.3 Experiment 10

The possibility of practice effects in Experiment 9 may not only have confounded the effect of cue size, but may also reduce the interaction effects with SOA and eccentricity. In this experiment, this aspect is addressed by randomly presenting each cue size condition within the same session. In addition, the ability to reduce and maintain attentional focus is further explored by introducing an invalid cue condition. To ensure the task does not become too complex and to allow the findings to be compared to the previous studies in the literature, stimuli in Experiment 10 will be presented only in the LVF and RVF.

10.3.1 Method

Participants

Participants included eleven control participants and the five ADys cases who participated in Experiment 8.

Apparatus and procedure

The apparatus was the same as previous experiments. The procedure was similar to that in Experiment 9, with the following exceptions: (i) an invalid-cueing condition was included in which both the cue and target were presented either to the left or right visual fields (that is, cue and target did not cross
Experiment 10 was conducted over three sessions separated by approximately 10 minute breaks. Each session contained 3 blocks of 324 trials: 60% valid, 30% invalid and 10% catch. For the two smaller cues (0.5° and 1°), presented at 3° eccentricity, there were two possible invalid-target positions at 1° and 7° eccentricities. See Figure 10.7.

Figure 10.7: An example of the invalid-cue procedure (cue at 3° eccentricity and target at 7° eccentricity) presented on the right of fixation. The broken circle represents the other possible location for target presentation.

10.3.2 Results

Response times (RTs) less than 100 msec were excluded as anticipations, and trials where timeouts occurred were also excluded from analysis. No participant responded to more than 5% of catch trials. The total amount of data removed in the screening process for the remaining data was approximately 2%.

A: Valid condition

Two RM-ANOVAs were conducted on RTs to systematically examine effects at 1° and 3° eccentricity, followed by those at 3° and 7° eccentricity.
At 1° and 3° eccentricity the within-subjects factors were cue size (0.5°, 1°), SOA (100 msec, 400 msec), eccentricity (1°, 3°) and visual field (LVF, RVF). The between-subjects factor was group (control, ADys). The difference between overall mean RTs for the ADys group (373 msec) and the control group (337 msec) approached significance (F(1, 14) = 3.9, p = 0.07). There were significant main effects of cue size (F(1, 14) = 13.4, p < 0.01) and SOA (F(1, 14) = 26.3, p < 0.001). Significant interactions were also observed for SOA × cue size × eccentricity (F(1, 14) = 9.5, p < 0.01), and SOA × cue size × eccentricity × group (F(1, 14) = 9.6, p < 0.01). Data are presented in Figure 10.8.

At 3° and 7° eccentricity the within-subjects factors were cue size (0.5°, 1°, 3°), SOA (100 msec, 400 msec), eccentricity (3°, 7°) and visual field (LVF, RVF). The between-subjects factor was group (control, ADys). The overall mean RT for the ADys group (381 msec) was significantly slower than the control group (339 msec; F(1, 14) = 4.8, p < 0.05). There were significant main effects of cue size (F(2, 28) = 4.9, p < 0.05), SOA (F(1, 14) = 29.3, p < 0.001) and eccentricity (F(1, 14) = 28.4, p < 0.001), and significant interactions for SOA × cue size (F(2, 28) = 4.7, p < 0.05), eccentricity × group (F(1, 14) = 23.8, p < 0.001), SOA × cue size × eccentricity (F(2, 28) = 8.6, p < 0.01), and SOA × cue size × eccentricity × group (F(1, 14) = 5.7, p < 0.01). Data are presented in Figure 10.8.

**SOA × cue size × eccentricity × group interaction:** To investigate the SOA × cue size × eccentricity × group interaction, data were analysed separately for each group in each cue size condition. A significant main effect of SOA was observed for the control group for each cue size, (0.5° cue = F(1, 10) = 50.9, p < 0.001; 1° cue = F(1, 10) = 13.1, p < 0.01; 3° cue = F(1, 10) = 15.5, p < 0.01), indicating a faster RT at the longer SOA. For the ADys group with a 0.5° cue size there was a significant main effect of SOA (F(1, 4) = 10.6, p < 0.05), eccentricity (F(1, 4) = 7.5, p < 0.05), and a significant interaction for
eccentricity × SOA ($F(1, 4) = 9.7, p < 0.01$). Paired sample $t$-tests indicated RTs were slower as eccentricity increased from $1^\circ$ to $3^\circ$ (by 14 msec, $t(4) = 2.9$, $p < 0.05$), and from $3^\circ$ to $7^\circ$ (by 14 msec, $t(4) = 4.4$, $p < 0.05$). Furthermore, RTs were significantly faster for longer SOA only at $1^\circ$ eccentricity ($t(4) = 3.1$, $p < 0.05$). For the $1^\circ$ and $3^\circ$ cues, the ADys group showed a significant main effect of eccentricity ($F(2, 8) = 7.1$, $p < 0.05$, and $F(1, 4) = 15.4$, $p < 0.05$, respectively). Paired sample $t$-tests indicated that RTs were slower as eccentricity increased from $3^\circ$ to $7^\circ$ for the $1^\circ$ cue (by 17 msec, $t(4) = 2.8$, $p < 0.05$), and for the $3^\circ$ cue (by 29 msec, $t(4) = 3.1$, $p < 0.05$). Furthermore, the changes in performance for the $1^\circ$ and $3^\circ$ cues were not significantly different.

Cue size effects in each SOA condition were also examined. At 100 msec SOA, the control group demonstrated slower RTs as cue size increased from $0.5^\circ$ to $1^\circ$ across each eccentricity. In contrast, although the ADys group demonstrated faster RTs as cue size increased from $0.5^\circ$ to $1^\circ$, this only occurred at $7^\circ$ eccentricity. At 400 msec SOA, there were no significant effects of cue size for either group.

ADys case-to-control group comparisons were made on conditions having...
shown significant group differences using the modified \( t \)-test with \( \alpha = 0.01 \).

All ADys cases (except GP) showed significantly slower RTs in the 0.5° cue condition as eccentricity increased from 1° to 3°. Only cases SM and GM showed significantly faster RTs in the 1° cue condition as eccentricity increased from 1° to 3°. All ADys cases showed significantly slower RTs in the 1° cue condition (except case TC), and 3° cue condition, as eccentricity increased from 3° to 7°. While all ADys cases showed a smaller benefit for longer SOA (than that of the control group), in the 3° cue condition at 7° eccentricity, this was only significantly smaller for cases SM, GM and TC. It should also be noted that case TC did not benefit from a longer SOA in any condition.

B: Orienting

A measure of orienting (RT cost) was calculated by subtracting the RT for a validly cued target from the RT for an invalidly cued target at the same location.

A RM-ANOVA was carried out on RT costs where the within-subject factors were cue size (0.5°, 1°), SOA (100 msec, 400 msec), eccentricity (1°, 3°) and visual field (LVF, RVF). (Note: An RT cost at 3° = the cost of shifting attention from the 3° eccentricity cue position to the 1° eccentricity target position.) The between-subject factor was group (control, ADys). The overall mean RT cost for the ADys group (4.5 msec) was significantly smaller than for the control group (24.7 msec; \( F(1,14) = 34.4, p < 0.001 \)). There was a significant main effect of SOA \( (F(1,14) = 8.5, p < 0.01) \), and also significant interactions for SOA×cue size \( (F(1,14) = 29.4, p < 0.001) \) and cue size×group \( (F(1,14) = 30.2, p < 0.001) \). These findings should be interpreted in light of the SOA×cue size×group interaction which was also significant \( (F(1,14) = 7.5, p < 0.05) \). Data are presented in Figure 10.9.
SOA × cue size × group interaction: Data were analysed separately for each group to investigate the SOA × cue size × group interaction. No significant main effects or interactions were observed for the control group, indicating that the effect of orienting remained consistent across conditions. For the ADys group, there were significant main effects of SOA ($F(1, 4) = 15.1, p < 0.05$) and cue size ($F(1, 4) = 22.4, p < 0.01$), as well as a significant SOA × cue size interaction ($F(1, 4) = 12.2, p < 0.05$). Follow-up analysis, using single sample t-tests, revealed that there was no significant effect of orienting for the 0.5° cue at either SOA. The effect of orienting reached significance for the 1° cue, but only with the 100 msec SOA. Independent sample t-tests comparing group performance indicated that the only set of conditions in which groups did not differ in orienting ability was for the 1° cue condition with a 100 msec SOA ($t(14) = 1.2, p > 0.2$).

![Graph](image)

Figure 10.9: Response time costs for the control and ADys groups as a function of stimulus onset asynchrony (SOA) for each cue size. Vertical bars represent SEM.

ADys case-to-control group comparisons were made on conditions having shown significant group differences using the modified t-test with $\alpha = 0.01$. The pattern of responses shown by all ADys cases was consistent with the group findings. That is, significant effects of orienting only occurred in the 100 msec SOA and 1° cue condition, which were comparable to the control group.
**Cue size\times eccentricity\times group interaction:** Interactions were observed for cue size\times eccentricity \(F(1, 14) = 14.5, p < 0.01\) and cue size\times eccentricity \times group \(F(1, 14) = 14.0, p < 0.01\). Data are presented in Figure 10.10. To investigate the cue size\times eccentricity \times group interaction, data were analysed separately for each group. No significant main effects or interactions were observed for the control group, indicating that the effect of orienting remained consistent across conditions. For the ADys group, there was a significant main effect of cue size \(F(1, 4) = 17.4, p < 0.01\), as well as a significant eccentricity\times cue size interaction \(F(1, 4) = 11.8, p < 0.05\). Follow-up analysis, revealed that there was no significant effect of orienting for the 0.5° cue size at either eccentricity, while the effect of orienting reached significance for the 1° cue size only at 1° eccentricity. Independent sample t-tests comparing group performance indicated that the only set of conditions in which groups did not differ in orienting ability was at 1° eccentricity with a 1° cue size \(t(14) = 1.5, p > 0.1\).

![Figure 10.10: Response time costs for the control and ADys groups as a function of eccentricity for each cue size. Vertical bars represent SEM.](image-url)

ADys case-to-control group comparisons were made on conditions having shown significant group differences using the modified t-test with \(\alpha = 0.01\). The pattern of responses shown by all ADys cases was consistent with the group findings. That is, significant effects of orienting only occurred in the
1° cue size at 1° eccentricity condition, which were comparable to the control group.

A further ANOVA was carried out on RT cost where the within-subjects factors were cue size (0.5°, 1°, 3°), SOA (100 msec, 400 msec), eccentricity (3°, 7°) and visual field (LVF, RVF). The between-subjects factor was group (control, ADys). (Note: An RT cost at 3° = cost of shifting attention from the 3° eccentricity cue position to the 7° eccentricity target position.) The overall mean RT cost for the ADys group (11.4 msec; s.e. = 3) was significantly lower than the control group (25.7 msec; s.e. = 2; p < 0.001). There were significant main effects of cue size (F(2,28) = 6.5, p < 0.01) and SOA (F(1,14) = 16.6, p < 0.01), and a significant eccentricity×group interaction (F(1,14) = 5.4, p < 0.05). Follow-up analysis revealed that performance was generally consistent across eccentricities for the control group, while for the ADys group, performance was better at 3° eccentricity than at 7° eccentricity.

Cue size×SOA×group interaction: There were also significant interactions of SOA×group (F(1,14) = 9.7, p < 0.01), cue size×group (F(2,28) = 13.2, p < 0.001) and cue size×SOA (F(2,28) = 10.8, p < 0.001). These findings should be interpreted in light of the significant cue size×SOA×group interaction (F(2,28) = 4.6, p < 0.05). Data are presented in Figure 10.11.

Figure 10.11: Response time costs for the control and ADys groups as a function of eccentricity and SOA for each cue size. Vertical bars represent SEM.
To investigate the cue size × SOA × group interaction, data were analysed separately for each group. No significant main effects or interactions were observed for the control group, indicating that the effect of orienting remained consistent across conditions. For the ADys group, there were significant main effects of cue size \((F(2, 8) = 15.1, p < 0.01)\) and SOA \((F(1, 4) = 17.3, p < 0.05)\), as well as a significant cue size × SOA interaction \((F(2, 8) = 23.8, p < 0.001)\). Follow-up analysis, using single sample \(t\)-tests, revealed that there was no significant effect of orienting for the 0.5° cue size at either SOA, while the effect of orienting reached significance for the 1° and 3° cue sizes only with the 100 msec SOA. Independent sample \(t\)-tests comparing group performance indicated that the groups did not differ in orienting ability with the 100 msec SOA for both the 1° and 3° cue sizes \((t(14) = 1.0, p > 0.3 \text{ and } t(14) = 0.6, p > 0.5, \text{ respectively})\).

ADys case-to-control group comparisons were made on conditions having shown significant group differences using the modified \(t\)-test with \(\alpha = 0.01\). The pattern of responses shown by all ADys cases was consistent with the group findings for the 0.5° cue size condition. That is, all showed significantly smaller orienting effects than the control group. For the 1° and 3° cue size conditions, all cases showed the same pattern of results as at the group level. That is, significant effects of orienting only occurred with the 100 msec SOA, which were comparable to the control group.

\textit{VF×cue size×group interaction}: A significant VF×cue size×group interaction \((F(2, 28) = 4.7, p < 0.05)\) was also observed. Data are presented in Figure 10.12. To investigate this interaction, data were analysed separately for each group. No significant main effects or interactions were observed for the control group, indicating that the effect of orienting remained consistent across conditions. For the ADys group, there was a significant main effect of cue size \((F(2, 8) = 14.3, p < 0.01)\), and a significant VF×cue size interaction \((F(2, 8) = 8.6, p < 0.05)\). Follow-up analysis, using single sample \(t\)-tests, re-
Figure 10.12: Response time costs for the control and ADys groups as a function of visual field for each cue size. Vertical bars represent SEM.

It was revealed that there was no significant effect of orienting for the 0.5° cue size in either VF, while the effect of orienting reached significance for the 1° and 3° cue sizes in the LVF, and also for the 3° cue size in the RVF. Independent sample t-tests comparing group performance in each condition confirmed that the groups did not differ in orienting ability in these conditions (smallest $p > 0.1$).

ADys case-to-control group comparisons were made using the modified t-test with $\alpha = 0.01$. All ADys cases showed poorer orienting ability than the control group for the 0.5° cue size in both visual fields. All cases showed orienting ability which was comparable to the control group in the LVF, except case TC for the 1° cue size. In the RVF, cases SW and GM performed within the 99% confidence interval of the control group for the 1° cue size, and all except case TC performed as well as the control group for the 3° cue size.

### 10.3.3 Discussion

This experiment compares the effects of manipulating cue size and SOA on target detection and attentional orienting in a group of adults with and without
The expected cue size effect, of longer RTs for target detection with increasing cue size (Castiello and Umilta, 1990; Turatto et al., 2000), was only observed for the control group for 0.5° and 1° cue size comparisons at the shorter SOA and at locations close to fixation (1° and 3°). This finding provides some support that there was some effect of practice responsible for the lack of cue size effect observed in Experiment 9. However, the cue size effect also appears to be partially determined by location of presentation and the SOA. For the ADys group, a reverse cue size effect was observed for 0.5° and 1° cue size comparisons at short SOA (100 msec) in the periphery (7°). That is, RTs to target detection were shorter as cue size increased. Neither group showed a cue size effect at the long SOA (400 msec). Taken together, these results do not support a visual acuity deficit in dyslexia as proposed by Evans et al. (1994).

Similarly, an effect of eccentricity on RT to target detection was not observed for the control group. While these findings may appear contradictory to previous experiments, the multiple scaling theory Poirier and Gurnsey (2005) may provide an explanation. According to this theory, unusual findings may be explained by underlying mechanisms (in a task) which have different rates of increase in the size of their receptive field properties as eccentricity increases. The inclusion of all cue sizes in a session may introduce a new receptive field property, and thus be responsible for the change of outcome seen in this experiment. Specifically, performance may become biased such that eccentricity effects are removed. An eccentricity effect consistent with the previous experiments was observed for the ADys group. Specifically, for the 1° and 3° cue sizes, RTs became slower as eccentricity increased from 3° to 7° and, for the 0.5° cue size, RTs became slower across all eccentricities. Faster RTs were observed with the 1° cue size as eccentricity increased from 1° to 3°. This finding suggests that the receptive field properties of individuals with dyslexia are not functioning in the same way as those of the control group.
With respect to the effect of increasing SOA, the pattern of results was consistent with those of Experiment 9. That is, both groups demonstrated improved performance with increased SOA although this was less so for the ADys group.

The results for the attentional orienting analysis indicate that this function remains consistent for the control group across varying SOA, cue size and eccentricity. However, clear difficulties were shown by the ADys group and each individual ADys case. For these individuals, orienting ability appears limited by the size of cue, SOA, eccentricity and visual field.

With respect to cue size, attentional orienting was not demonstrated with the 0.5° cue and the orienting that was demonstrated with the 1° cue decreased with eccentricity. The best performance was shown with the largest cue size of 3°. These findings suggest that attentional processing is poorer in the periphery, and the peripheral size of the attentional focus for individuals with dyslexia is larger than normal. Thus, it appears that two characteristics of orienting are susceptible: cue size and position of attentional focus.

Orienting ability for the individuals with dyslexia declined at the longer SOA (400 msec), which is consistent with the findings of Facoetti et al. (2000b, Expt 1). The defining consequence of increasing SOA appears to be that of allowing the attentional focus to expand, thus removing the response time cost usually associated with detecting an invalidly-cued target.

The apparent instability of attentional focus is further suggested by examining the results of the two conditions which required orienting to an invalid 1° cue at 3° eccentricity. When attention was required to shift to 7° eccentricity, the RT cost was 36 msec, whereas for shifts to 1° the RT cost was only 2 msec. Thus, the attentional focus seems to be ‘drifting’ toward fixation, requiring a change in direction for target detection at 7° eccentricity (a high RT cost) while encompassing the target at 1° eccentricity (a low RT cost). See Figure 10.13). This drift toward fixation may represent a natural movement
of attentional focus which occurs earlier for individuals with dyslexia.

Thus, the attentional system of individuals with dyslexia does not appear to be slower at directing attention to each successive stimulus (Brannan and Williams, 1987; Hari, Valta, and Uutela, 1999) but rather seems less able to maintain attention. This difficulty in maintaining attention appears related to both maintaining the size and the position of the attentional focus.

Visual field differences were observed, where the individuals with dyslexia generally showed poorer orienting ability in the right visual field, requiring the largest cue size before performance was comparable to the controls. These results do not support a “left mini-neglect” (Hari and Renvall, 2001) in adults with dyslexia. However, the current findings do suggest that the size of attentional focus in both visual fields is larger for individuals with dyslexia, with an additional difficulty associated with shifting attention in the right visual field.

### 10.4 Conclusions

The aim of the research presented in this chapter was to investigate whether dyslexia is associated with general or specific impairments of attention, and examine the effect of changing stimulus characteristics using a simple detection task.
One of the main findings of the present study indicated that, while the individuals with dyslexia showed generally slower performance than normal readers at detecting a target, cueing was effective in improving performance at all eccentricities. This finding is not consistent with those of Brannan and Williams (1987) or Facoetti et al. (2000b), which suggested difficulties in using a cue, therefore suggesting orienting difficulties in dyslexia. However, a major experimental difference between these and the present study should be noted - cueing only occurred within a single visual field in the present study. As such, performance may have improved for the dyslexia group due to an effective alerting component of attention, thus allowing the attentional focus to be reduced at least within the constraints of a single visual field. It has been previously demonstrated that this attentional component is functional in dyslexia (Buchholz and Aimola Davies, 2006).

Performance deficits were observed based on size of stimulus, timing of stimulus presentation and location of stimulus presentation.

The cue size effects observed in the individuals with dyslexia were not comparable to the normal reading group. In particular, orienting effects were only observed for the larger cue sizes (1° and 3°), such that there was only a small orienting effect for the largest cue size. These findings suggest that while the individuals with dyslexia are able to appropriately reduce their attentional focus, this focus is larger than that of normal readers.

Increasing SOA did not assist the individuals with dyslexia in detecting the target, at least not to the same extent as for the normal reading group. Furthermore, the individuals with dyslexia demonstrated a decline in the orienting effect as SOA increased. These findings indicate a difficulty in re-defining and maintaining attentional focus, and are consistent with those found in children with dyslexia (e.g., Facoetti et al., 2000b). In addition, there appeared to be a “drift” of the attentional focus toward fixation. This may reflect a strategy adopted when the processing of visual information cannot be maintained by the attentional system.
A visual field asymmetry was observed, for the individuals with dyslexia whereby orienting performance was poorer in the right visual field, with difficulties increasing as eccentricity from fixation increased.

The presence of a larger attentional focus may, as a proximal cause of dyslexia, be related to the difficulty individuals with dyslexia show in suppressing information surrounding a word to be read (Geiger, Lettvin, and Fahle, 1994; Rayner, Murphy, Henderson, and Pollatsek, 1989). As a distal cause, it may prevent accurate letter order encoding, and therefore prevent the learning of grapheme-phoneme mappings, resulting in a phonological processing difficulty. The findings of this study are consistent with the proposal of Wolford and Fowler (1984) that poor readers remain less flexible in reallocating attention to small components of a word. Furthermore, a difficulty in maintaining attentional focus may affect detailed visual processing. In reading, this is necessary for words to be fully processed (LaBerge and Brown, 1989). Finally, the increased difficulty in orienting to the periphery, more-so in the right visual field, affects the amount of useful information that can be obtained and analysed between fixations during reading (Bertera and Rayner, 2000; Schroyens et al., 1999). This attentional difficulty may be indicative of top-down higher-level processing deficits in the inferior parietal cortex which has been implicated in covert shifts of attention (Wilson, Woldorff, and Mangun, 2005).

In conclusion, the orienting attentional difficulties observed in dyslexia appear to be related specifically to reducing and maintaining attentional focus. Furthermore, as shown in the experiments in this study these difficulties are observable at increasing eccentricities, smaller cue sizes and longer SOAs. These difficulties appear magnified in the periphery, particularly in the right visual field. Reading may be compromised since a difficulty in automatic orienting may affect the planning of eye movements, while a difficulty maintaining attention may hinder decoding due to increased distraction from nearby text. Overall, this research supports the hypothesis that the variable findings of an
orienting deficit in dyslexia in previous research may be explained by the use of different methodologies. This highlights the need to consider specific task variables when designing attentional studies.
Chapter 10: Characterising the attentional deficits
Chapter 11

General discussion

The apparent heterogeneity of visual and auditory processing deficits shown by individuals with dyslexia has led researchers to propose several hypotheses of dyslexia. In this thesis I have specifically examined the visual attention hypothesis of dyslexia.

11.1 Profile of adults with dyslexia

Several visual attentional experiments examining performance of adults with dyslexia have been presented, with analysis of group comparisons and also individual case to control group comparisons. The first seven experiments (Chapters 4-9) were carried out using previously developed tests of visual attention. In summary, a deficit in visual selective attention was demonstrated by the dyslexia cases in Chapter 4, as indicated by a difficulty in target detection when visual search involved a conjunction of stimulus features. Chapter 5 examined attentional dwell time, and the results suggested that: a) AB performance is dependent on task requirements, and b) the attentional system is compromised in dyslexia. However, the variability of individual case performance also suggests that prolonged attentional dwell time is not a core deficit
in dyslexia. In Chapter 6, the adults with dyslexia demonstrated a difficulty in both the space-based and the object-based components of covert visual attention, most specifically problems were found with stimuli located in the periphery. Chapter 8 examined the roles of visual attention (covert and overt) and auditory memory processes in dyslexia. All dyslexia cases demonstrated difficulty with covert shifts of attention toward and away from fixation. The results also indicated that deficits in overt visual attentional processing (case TC) and auditory working memory (case JM) can be present with dyslexia, but neither is a necessary requirement. Chapter 9 examined the alerting, orienting and executive control components of attention. Performance on two tasks were compared: one a detection task and the other a discrimination task. All ADys cases demonstrated difficulties only with orienting attention, and this was shown to be specific to the periphery. However, while orienting to parafoveal stimuli was intact for the detection task, it was found to be impaired for the discrimination task.

Based on the findings of these experiments, and previous research, it was clear that observing the attentional orienting difficulties in dyslexia was dependent on differences in methodological characteristics. The final three experiments (Chapter 10) used a newly developed paradigm in which several stimulus characteristics were manipulated within a single session of testing. Taken together, the results indicate that all individuals with dyslexia present with covert visual selective attentional difficulties related to visual orienting of attention, specific to adjusting and maintaining the attentional focus. These difficulties appear greater in the right visual field. A profile of the results obtained in this research is presented in Table 11.1.
Table 11.1: Attentional profile of dyslexia individuals. Performance compared to the control group: (✓) = no difficulty experienced, (×) = difficulty experienced, (-) = no testing carried out.

<table>
<thead>
<tr>
<th></th>
<th>GP</th>
<th>SM</th>
<th>SW</th>
<th>GM</th>
<th>TC</th>
<th>JM</th>
<th>RM</th>
<th>TM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visual selective attention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covert</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Overt</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Attentional blink</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T = coloured digit</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T = letter</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Alerting</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Orienting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOA = 100 msec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fovea (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fovea (cue size = 1°)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parafovea (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parafovea (cue size &gt; 1°)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Periphery (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Periphery (cue size &gt; 1°)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SOA = 400msec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fovea (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fovea (cue size = 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parafovea (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Parafovea (cue size &gt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Periphery (cue size &lt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Periphery (cue size &gt; 1°)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>LVF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cue size &lt; 1°</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cue size = 1°</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cue size &gt; 1°</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>RVF</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cue size &lt; 1°</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cue size = 1°</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>cue size &gt; 1°</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Executive control</strong></td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Auditory selective attention</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Divided attention</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td><strong>Sustained attention</strong></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Other deficits were not shown consistently across all individual cases and therefore would not be considered core to dyslexia. Implications of the findings for accounts of the processes of reading and learning to read, and future directions of research are discussed.

### 11.2 Implications of findings for reading

Covert attention has been shown to affect both spatial and temporal aspects of visual processing (Carrasco et al., 1998, 2000; Carrasco and McElree, 2001; Desimone et al., 1995; Kinchla, 1992; Lu and Dosher, 1998; Nakayama and Mackeben, 1989; Palmer, 1994; Posner, 1980; Prinzmetal et al., 1998; Reynolds and Desimone, 1999; Shiu and Pashler, 1994; Treue and Trujillo, 1999; Yeshurun and Carrasco, 1999). Physiological evidence provides support for an attentional effect on the quality of sensory representations (Desimone et al., 1995; Reynolds and Desimone, 1999; Treue and Trujillo, 1999). Thus attentional deficits would be expected to affect various aspects of the reading process, and may be both a proximal and distal cause of dyslexia. That is, as a distal cause, poor attentional processes may hinder the development of the reading system. As a proximal cause, poor attentional processes may directly impair the ability of the individuals with dyslexia to perceive and direct attention to the reading text in a way that is useful for processing each word.

The ability to focus and respond to rapidly presented stimuli is considered important to individual survival (by avoiding being hit by a projectile) and develops independently of reading. Although the development of this ability does not rely on reading, it may be related to the development of and/or proper functioning of the reading system. For example, reading requires the spatial selection of successive words in a given text, together with coordination of this process with eye movements. Readers obtain useful information not only from the fixated word, but also from the next word in the text. When a word is visible prior to fixation, less time is spent viewing it, a phenomenon known
as parafoveal preview benefit (see Rayner, 1998, for review). This benefit is reduced or removed when the reader finds it difficult to, or is unable to, engage stimuli parafoveally. One possible consequence to a developing reading system is that, because attention is unable to remain focused on word parts, it becomes more difficult to make the visual/verbal (letter-sound) correspondences required to learn the phonological representations of new words and integrate them into memory. Thus visual attention difficulties may operate as a distal cause to the phonological difficulties seen in dyslexia.

Another possibility for the role of visual attentional difficulties in the reading process is that the processing of word parts is slowed. Reducing attentional focus size allows distracting information to be minimized during reading, and therefore local word information (letters) can be processed quickly and accurately. If the size to which the attentional focus can be reduced is, at the same time, both limited and dependent on location in space, the slowed processing of visual information and the greater confusion across words make it difficult to access the phonological representations. The result is an increase in reading errors. Thus visual attention difficulties may operate as a proximal cause to the phonological difficulties seen in dyslexia. The development and use of a sight word vocabulary (irregular and regular words) relies on global processing of a word and therefore would not be expected to be affected by an inability to maintain focused attention on word parts. Recently, findings presented by Valdois and colleagues (2004) were consistent with cases of surface dyslexia having difficulty in expanding the attentional focus. The difficulties shown by the phonological and surface subtypes may represent the same fundamental problem, that is, a difficulty in adjusting attentional focus. Further research examining the performance of subtypes of dyslexia on tasks requiring focused and global attentional processes is needed.


11.3 Future directions

In the following sections I present several areas where future research may extend current knowledge. I have limited this discussion to those areas most directly related to the theme of this thesis.

11.3.1 Attention and magnocellular function

A causal relationship between magnocellular and attentional deficits is generally accepted amongst researchers of attentional processes in dyslexia. However, the nature of this relationship remains speculative. Research, with non-dyslexic individuals, has provided a basis from which to examine the role attentional processing has in the magnocellular functions of motion processing and contrast sensitivity.

Motion coherence

The processing of various sensory properties, including motion, have been shown to be modulated by visual attention. For example, attentional effects have been shown with motion extrapolation (Kerzel, 2003; Verghese and McKee, 2002); speed discrimination (Saenz, Buracas, and Boynton, 2002); motion contrast (Raymond, 2000) and the motion aftereffect (Alais and Blake, 1999; Chaudhuri, 1990; Vidnyanszky, Blaser, and Papathomas, 2002). In addition, attention is involved in the perception of “third-order” motion, in which attentional tracking generates coherent motion where none is present (Cavanagh, 1992; Lu and Sperling, 1995). In a study of non-dyslexic individuals, Melcher et al. (2004) investigated the role of spatial attention in a double-motion task by adding a concurrent colour contrast discrimination task. While the differences in the summation constant for central and peripheral targets was greatly reduced with the additional task, no changes were observed in overall motion sensitivity. The authors concluded that attention appears to specifically mod-
ulate temporal summation, which further suggests that the long integration times found for motion coherence are mediated by attention, specifically sustained attention.

It appears from the findings of the research in this thesis that not all dyslexia individuals exhibit difficulties in sustained attention (as demonstrated by the findings that only one dyslexia case, GM, showed a performance deficit on the Lottery subtest of the TEA). If this attentional ability is directly related to identification of coherent motion then a larger study may determine a correlation between the two abilities. Furthermore, should a relationship be found, the inconsistent findings in the literature of a magnocellular deficit may be explained by individuals with sustained attention deficits in the dyslexia group samples being represented differently.

**Contrast sensitivity**

Recent evidence has shown that paying attention shifts the contrast-response function. Neural responses, in area V4 (Reynolds, Pasternak, and Desimone, 2000) and MT (Martinez-Trujillo and Treue, 2002), to low-contrast stimuli become comparable to those elicited by an unattended higher-contrast stimuli. However, there has been little research carried out of the psychophysical interactions of contrast and visual attention. Pashler et al. (2004) examined this issue using a visual search task in which the participants selected objects based on contrast. The ability to attend selectively to low versus high contrast items suggests that selectivity for stimulus contrast might be similar to other types of feature selectivity (e.g., colour and location).

It appears from the findings of the research in this thesis that all individuals with dyslexia (who show phonological difficulties) exhibit difficulties in covert (without eye movements) visual selective attention. Given the findings of Pashler et al. (2004), it may be expected that each would also demonstrate contrast sensitivity differences to those of a control group. The inconsistent
findings of contrast sensitivity differences in previous research has been sug-
gested to be related to subgroup representation in the dyslexia groups studied
(Borsting et al., 1996; Hogben, 1996). Further research examining covert vi-
sual selective attention and contrast sensitivity may provide insight into the
relationships of deficit in these processes to the different subtypes of dyslexia.

Dyslexia research examining the relationship between sustained attention
deficits and performance on coherent motion tasks, and visual selective atten-
tion and contrast sensitivity, may also provide further insight into the rela-
tionship between visual attention, magnocellular processes and the subtypes
of dyslexia.

11.3.2 Other parietal cortex functions

Visual processes

In this thesis I have focussed on visuospatial attention processes in dyslexia.
Eye movement control functions in individuals with dyslexia has been exten-
sively examined in previous research (e.g., Eden, Stein, Wood, and Wood, 1994;
Griffen, Christenson, Wesson, and Erickson, 1998; Stein, Riddell, and Fowler,
1988). Other parietal cortex functions related to the visual modality include
visually guided movements (e.g., Pisella et al., 2000) and mental rotation (e.g.,
Harris et al., 2000; Milivojevic et al., 2003).

Visually guided movements. It is thought that during visually guided move-
ment, visual information necessary for immediate use in fast motor actions is
extracted from the visual streams, and relies on computations made mainly in
the dorsal stream (Goodale et al., 2004). Therefore, dysfunctions of the pari-
etal lobe may be expected to result in poor performance on tasks requiring
visuomotor control.

In a recent study of patients with optic ataxia (Schindler et al., 2004), par-
Participants were required to reach between two vertical cylinders whose location varied on each trial. These researchers found that control participants reached through the midpoint between the two cylinders as if trying to avoid the cylinders. The patients, however, appeared to ignore the cylinders reaching along the path independently of the positions of the cylinders. If the deficits observed in dyslexia are the result of a general parietal dysfunction then it would be predicted that individuals with dyslexia would demonstrate performance deficits on this task similar to the patients with ataxia. To my knowledge no such studies have been carried out to date.

Mental rotation. Few studies have examined the ability of individuals with dyslexia to differentiate between normal and mirrored stimuli which have been rotated. An early study by Corballis et al. (1985), requiring discrimination between the letters ‘b’ and ‘d’ at varying angular rotations, found no performance differences between a dyslexia group and a non-dyslexia group of children. In contrast, Brendler and Lachmann (2001) found that children, with specific difficulties in reading, demonstrated difficulties in differentiating objects of the same form but of different orientation. More recently, Rusiak et al. (2007) reported that individuals with dyslexia were slower to discriminate between normal and mirrored letters than a control group. However, these individuals also demonstrated increased response times with increasing angle of rotation, comparable to that of the control group. These findings suggested to the researchers that individuals with dyslexia were able to perform mental rotation but that other processes were responsible for the observed slowness. They suggested that this may be due to the requirement to extract information from long-term memory, namely letter names. Further research is clearly required to determine if the deficits are related to the degree of language impairment and/or the specific subtype of dyslexia.

Dyslexia research examining the additional parietal functions of visuomotor control and mental rotation may provide further insight into the gen-
erality of parietal dysfunction. The relationship between these functions and the level of reading impairment, as well as the subtype of dyslexia, may also be explored.

**Auditory attention**

Attentional mechanisms are not limited to the visual system. Evidence that there are covert attentional systems common to spatial orienting as well as orienting to language comes from studies of patients with parietal lesions. When these patients were required to monitor a stream of auditory information for a sound, they were slowed in their ability to orient toward a visual cue. The effects of the language task differed from the visual task in that they were bilateral rather than on the side opposite the lesion. Based on this study, Posner and Cohen (1987) suggested that visual orienting involves attentional mechanisms interconnected with those used for language processing. Similar results were found using a non-clinical sample (Posner et al., 1989).

Reading is a learned process which taxes both the auditory and visual attentional systems. It has been demonstrated that both auditory and visual inputs converge on the parietal cortex (Farah et al., 1989), and the presence of cells acting across both modalities have been reported in this area (Anderson et al., 1995). Thus, the parietal cortex may have a role orienting attention in the auditory modality, in addition to the visual modality (Vidyasagar, 1999). Evidence that selective spatial attention may facilitate auditory perception has been provided by several studies which have demonstrated the influence of spatial distribution of auditory attention on phoneme identification (Mondor and Bryden, 1991, 1992). Asbjornsen and Bryden (1998) have provided evidence of an auditory spatial selection deficit in individuals with dyslexia. Recently, Facoetti and colleagues (Facoetti et al., 2003) reported both auditory and visual deficits in children with dyslexia associated with automatic orienting of spatial attention. They suggest that the development of phonological or
orthographic representations may have been distorted as a result of a global selective spatial attention deficit, thus impairing reading ability. Auditory selective attention deficits were only seen in one of the ADys cases presented in this thesis (case JM on the Elevator Counting with Distraction subtest of the TEA). This finding is particularly interesting because this task also has a large auditory (verbal) memory component. While several studies have examined each of these components (e.g., Asbjornsen and Bryden, 1998; Tijms, 2004), further investigations are required to determine which component of this deficit might allow further delineation of dyslexia.

**Imaging studies**

Evidence for the involvement of the parietal cortex in visuospatial attentional processes is extensive. Electrophysiological investigations in macaques have found significant attentional modulation in the activity of neurones in posterior parietal cortex (PPC), and middle temporal motion area (MT/V5) (Luck et al., 1997; Motter, 1993; Steinmetz and Constantinidis, 1995; Treue and Maunsell, 1996). Positron emission tomography (PET) studies have indicated that regions of the parietal cortex are activated when individuals shift attention to different regions of the visual field (Corbetta et al., 1995; Nobre et al., 1997). Recently, Yantis et al. (2002) examined the brain activity of neurologically normal individuals as they covertly shifted attention between two peripheral spatial locations. They found that the activity of sub-regions of the parietal cortex, namely the right superior parietal lobule (SPL) and right inferior parietal lobule (IPL), were involved specifically with shifting attention. The findings in this thesis, of an attentional shift deficit in individuals with dyslexia, suggest specific deficits in the functioning of one or both of these parietal regions. Further investigations, using fMRI during attentional tasks, would provide important information about compromised brain areas in individuals with dyslexia.
11.3.3 Other brain areas

With the development of improved brain imaging techniques, researchers have distinguished abnormalities in other brain areas of individuals with dyslexia. In the following sections I present two of the current proposals of alternate, or parallel, brain areas responsible for the difficulties observed in dyslexia.

Corpus callosum

It has been suggested that the reading difficulties shown by individuals with dyslexia are a result of abnormal functioning of the corpus callosum (CC), specifically in interhemispheric communication. Since reading requires the integration of component processes involving both hemispheres, a disruption in normal CC function would lead to less efficient reading.

Individuals with dyslexia have shown both anatomical (Brambilla et al., 2005; Duara et al., 1991; Hynd, 1995; Robichon and Habib, 1998; Rumsey et al., 1996; von Plessen et al., 2002) and functional differences in their CC compared to individuals without dyslexia (Boles and Turan, 2003; Heim and Keil, 2004; Walker et al., 2001). Furthermore, Robichon and Habib (1998) found a significant correlation between the callosal differences and degree of phonological impairment shown by their group of adults with dyslexia (see also Hynd, 1995). In a recent study, functional lateralisation of lexical decision processes has been shown to be associated with measures of performance on language tasks, such as vocabulary and reading comprehension (Weems and Zaidel, 2004). Finally, Davidson and Saron (1992) reported that, compared to a control group, children with dyslexia demonstrated a faster inter-hemispheric transfer time (IHTT) from the right hemisphere (RH) to the left hemisphere (LH) and a slower IHTT in the reverse direction. Furthermore, the faster left-to-right transfer was associated with poorer reading and language functions (see also Davidson, Leslie, and Saron, 1990). These findings support the view that dyslexia might be, at least in part, due to a particular disconnection
syndrome between the cerebral hemispheres (Mather, 2001).

A role for the CC in visual attention has been demonstrated in studies of split-brain patients whose corpus callosum had been sectioned as treatment for intractable epilepsy (Afrasz et al., 2003; Corballis, 1995; Ellenberg and Sperry, 1979), and in individuals with agenesis of the corpus callosum (Hines et al., 2002). Hemispheric interactions have also been reported to be ostensibly related to performance on tasks examining selective visual attention (Banich, 1998), and attentional focus (Merola and Liederman, 1990; Mikels and Reuten-Lorenz, 2004; Sohn et al., 1996; Weissman and Banich, 1999) of neurologically normal individuals.

Taken together, research to date suggests that further studies are required to investigate the relationship between interhemispheric transfer, hemispheric interactions, visual attentional processes, and literacy.

Cerebellum

A relatively new theory of dyslexia proposes a causal effect of cerebellar deficits (Nicolson, Fawcett, and Dean, 2001). Cerebral dysfunction has been shown to impair several cognitive processes such as linguistic processing, abstract thinking and automatisation of learned procedures (e.g., Krupa, Thompson, and Thompson, 1993). There are many reciprocal projections between the cerebellum and different structures of the brain, for example, to Broca’s area or to the parietal cortex, which are thought most likely responsible for the wide range of cerebellar functions (Ackerman and Cianciolo, 2000; Fabbro, 2001; Silveri et al., 2000).

Functional deficits have been demonstrated in individuals with dyslexia consistent with compromised cerebellar function. For example, problems with postural stability (Fawcett and Nicolson, 1999), automatisation of skills (Nicolson and Fawcett, 1999; Overy et al., 2003), time estimation (Nicolson, Fawcett, and Dean, 1995), speeded performance (Nicolson and Fawcett, 1994), and eye
blink conditioning (Nicolson et al., 2002) have been reported. Several researchers have reported anatomical anomalies within the cerebellum, many reporting an atypical symmetry of the hemispheres (Finch et al., 2002; Krupa et al., 1993; Rae et al., 2002). Generally, a larger right cerebellar hemisphere is found in neurologically normal individuals.

Several questions have been raised with respect to the relationship of the cerebellar deficits with observed magnocellular/parietal deficits. Nicolson, Fawcett, and Dean (2001) suggest that a “cerebellar deficit is an alternative, or parallel, mechanism to magnocellular abnormality” (pg. 510). Some researchers have suggested that parietal deficits may better explain some of the problems of individuals with dyslexia found by Nicolson and Fawcett. For example, it has been reported that, under multitask conditions, the inability to allocate sufficient attention to postural control may contribute to imbalance (Marsh and Geel, 2000; Redfern, Jennings, Martin, and Furman, 2001; Teasdale and Simoneau, 2001).

Little is known about co-occurrence of cerebellar and parietal functional deficits. Further research is required to investigate the relationship between these, and their association with literacy.
11.4 Conclusions

In this thesis I have presented several experiments which have examined the performance of individuals with dyslexia on tasks requiring visual attention. When examined as a group, consistent attentional deficits were observed across all tasks. However, group measures were not always representative of individual case measures, thus highlighting the importance of examining individual performance in conjunction with group performance on various aspects of attentional function.

I have also presented possible areas where these attentional difficulties could affect the processes of reading and learning to read itself (that is, the development of the reading process). It is suggested that visual attentional deficits play a significant role in the reading difficulties observed in these individuals, possibly being the factor responsible for a lack of development of phonological skills, which in turn cause reading system abnormalities — the proximal cause of phonological dyslexia.
CHAPTER 11: GENERAL DISCUSSION
Appendix A1 : From Au and Lovegrove (2001)

<table>
<thead>
<tr>
<th>practice</th>
<th>List 1</th>
<th>List 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ab</td>
<td>gop</td>
<td>ted</td>
</tr>
<tr>
<td>yox</td>
<td>nad</td>
<td>lif</td>
</tr>
<tr>
<td>rez</td>
<td>sut</td>
<td>thim</td>
</tr>
<tr>
<td>pid</td>
<td>phot</td>
<td>chut</td>
</tr>
<tr>
<td>mell</td>
<td>sith</td>
<td>giph</td>
</tr>
<tr>
<td>feap</td>
<td>hoil</td>
<td>toud</td>
</tr>
<tr>
<td>knap</td>
<td>gead</td>
<td>daul</td>
</tr>
<tr>
<td>hend</td>
<td>prin</td>
<td>stet</td>
</tr>
<tr>
<td>hundy</td>
<td>mulp</td>
<td>roin</td>
</tr>
<tr>
<td>eldop</td>
<td>nint</td>
<td>gren</td>
</tr>
<tr>
<td>wotfob</td>
<td>gurdet</td>
<td>torlep</td>
</tr>
<tr>
<td>biftel</td>
<td>tadlen</td>
<td>latsar</td>
</tr>
<tr>
<td></td>
<td>polmex</td>
<td>tashet</td>
</tr>
<tr>
<td></td>
<td>sothep</td>
<td>miphic</td>
</tr>
<tr>
<td></td>
<td>lishon</td>
<td>dethix</td>
</tr>
<tr>
<td></td>
<td>rayed</td>
<td>coge</td>
</tr>
<tr>
<td></td>
<td>squow</td>
<td>byrcal</td>
</tr>
<tr>
<td></td>
<td>mieb</td>
<td>phigh</td>
</tr>
<tr>
<td></td>
<td>hudned</td>
<td>quog</td>
</tr>
<tr>
<td></td>
<td>lindify</td>
<td>pnir</td>
</tr>
<tr>
<td></td>
<td>cythe</td>
<td>throbe</td>
</tr>
<tr>
<td></td>
<td>nolhod</td>
<td>sloy</td>
</tr>
<tr>
<td></td>
<td>cedge</td>
<td>depine</td>
</tr>
<tr>
<td></td>
<td>whumb</td>
<td>lunap</td>
</tr>
<tr>
<td></td>
<td>knoink</td>
<td>dinlan</td>
</tr>
<tr>
<td></td>
<td>expram</td>
<td>rhunk</td>
</tr>
<tr>
<td></td>
<td>dreek</td>
<td>imbaf</td>
</tr>
<tr>
<td></td>
<td>brecked</td>
<td>glack</td>
</tr>
<tr>
<td></td>
<td>wroucht</td>
<td>zoath</td>
</tr>
<tr>
<td></td>
<td>rejuwe</td>
<td>pertome</td>
</tr>
</tbody>
</table>
Appendix B1: Castles, Coltheart and Bates test of reading (Bates et al., 2003)

<table>
<thead>
<tr>
<th>Regular</th>
<th>Irregular</th>
<th>Nonwords</th>
</tr>
</thead>
<tbody>
<tr>
<td>bed</td>
<td>blood</td>
<td>aspy</td>
</tr>
<tr>
<td>brandy</td>
<td>bouquet</td>
<td>baft</td>
</tr>
<tr>
<td>caddy</td>
<td>bowl</td>
<td>bleaner</td>
</tr>
<tr>
<td>chance</td>
<td>break</td>
<td>blick</td>
</tr>
<tr>
<td>check</td>
<td>ceiling</td>
<td>boril</td>
</tr>
<tr>
<td>chicken</td>
<td>cello</td>
<td>borp</td>
</tr>
<tr>
<td>context</td>
<td>chamois</td>
<td>brennet</td>
</tr>
<tr>
<td>cord</td>
<td>chassis</td>
<td>brinth</td>
</tr>
<tr>
<td>creole</td>
<td>choir</td>
<td>crat</td>
</tr>
<tr>
<td>crux</td>
<td>colonel</td>
<td>delk</td>
</tr>
<tr>
<td>curb</td>
<td>come</td>
<td>doash</td>
</tr>
<tr>
<td>drop</td>
<td>cough</td>
<td>drick</td>
</tr>
<tr>
<td>flannel</td>
<td>couple</td>
<td>farl</td>
</tr>
<tr>
<td>free</td>
<td>crépe</td>
<td>floatchtwail</td>
</tr>
<tr>
<td>give</td>
<td>deaf</td>
<td>framp</td>
</tr>
<tr>
<td>grail</td>
<td>depot</td>
<td>ganten</td>
</tr>
<tr>
<td>hand</td>
<td>eye</td>
<td>gop</td>
</tr>
<tr>
<td>inset</td>
<td>friend</td>
<td>grenty</td>
</tr>
<tr>
<td>life</td>
<td>gauge</td>
<td>gurve</td>
</tr>
<tr>
<td>long</td>
<td>genre</td>
<td>gwextoint</td>
</tr>
<tr>
<td>luck</td>
<td>gist</td>
<td>hest</td>
</tr>
<tr>
<td>magnate</td>
<td>good</td>
<td>morshab</td>
</tr>
<tr>
<td>market</td>
<td>head</td>
<td>norf</td>
</tr>
<tr>
<td>marsh</td>
<td>iron</td>
<td>peef</td>
</tr>
<tr>
<td>mist</td>
<td>island</td>
<td>peng</td>
</tr>
<tr>
<td>mustang</td>
<td>lose</td>
<td>phleptish</td>
</tr>
<tr>
<td>navy</td>
<td>mauve</td>
<td>pite</td>
</tr>
<tr>
<td>need</td>
<td>meringue</td>
<td>pleech</td>
</tr>
<tr>
<td>nerve</td>
<td>middle</td>
<td>pofe</td>
</tr>
<tr>
<td>peril</td>
<td>routine</td>
<td>rint</td>
</tr>
<tr>
<td>plant</td>
<td>shoe</td>
<td>seldent</td>
</tr>
<tr>
<td>pump</td>
<td>shove</td>
<td>shoathe</td>
</tr>
<tr>
<td>quaver</td>
<td>soiree</td>
<td>spatch</td>
</tr>
<tr>
<td>sleek</td>
<td>soul</td>
<td>spoltchurb</td>
</tr>
<tr>
<td>stench</td>
<td>sure</td>
<td>stendle</td>
</tr>
<tr>
<td>tail</td>
<td>tomb</td>
<td>streamshelth</td>
</tr>
<tr>
<td>take</td>
<td>wolf</td>
<td>tapple</td>
</tr>
<tr>
<td>vista</td>
<td>work</td>
<td>tharque</td>
</tr>
<tr>
<td>weasel</td>
<td>yacht</td>
<td>thurnlurse</td>
</tr>
<tr>
<td>wedding</td>
<td>zealot</td>
<td>trofe</td>
</tr>
</tbody>
</table>
Appendix B2: Regular and irregular-word spelling measure

<table>
<thead>
<tr>
<th>Target word</th>
<th>Acceptable spellings</th>
</tr>
</thead>
<tbody>
<tr>
<td>shovel*</td>
<td>spread*</td>
</tr>
<tr>
<td>lymph*</td>
<td>gnome*</td>
</tr>
<tr>
<td>dog</td>
<td>loin</td>
</tr>
<tr>
<td>shin</td>
<td>plaid*</td>
</tr>
<tr>
<td>mesh</td>
<td>gnome*</td>
</tr>
<tr>
<td>scream*</td>
<td>sign*</td>
</tr>
<tr>
<td>tinge</td>
<td>vim</td>
</tr>
<tr>
<td>hunch</td>
<td>void</td>
</tr>
<tr>
<td>zip</td>
<td>rhyme*</td>
</tr>
<tr>
<td>spread</td>
<td>spred</td>
</tr>
<tr>
<td>sign</td>
<td>sine</td>
</tr>
<tr>
<td>scream</td>
<td>skreem or screem</td>
</tr>
<tr>
<td>dwarf</td>
<td>dwarf</td>
</tr>
<tr>
<td>bald</td>
<td>balled or borld</td>
</tr>
<tr>
<td>niche</td>
<td>nish or neesh</td>
</tr>
<tr>
<td>chrome</td>
<td>crome or croam or krome or kroam</td>
</tr>
<tr>
<td>plaid</td>
<td>plad</td>
</tr>
<tr>
<td>sieve</td>
<td>sive or siv</td>
</tr>
<tr>
<td>rhyme</td>
<td>rime</td>
</tr>
<tr>
<td>wand</td>
<td>wond</td>
</tr>
<tr>
<td>shove</td>
<td>shuv</td>
</tr>
<tr>
<td>crypt</td>
<td>kript</td>
</tr>
<tr>
<td>gnome</td>
<td>nome or noam</td>
</tr>
<tr>
<td>lymph</td>
<td>limf</td>
</tr>
<tr>
<td>ghoul</td>
<td>gool</td>
</tr>
<tr>
<td>goad</td>
<td>goed</td>
</tr>
<tr>
<td>cinch</td>
<td>sinch</td>
</tr>
</tbody>
</table>

NB: Words which are irregular for spelling are asterisked (*), unmarked items are regular for spelling.

Appendix B3: “Spell it as it sounds” regularised spelling measure

<table>
<thead>
<tr>
<th>Target word</th>
<th>Acceptable spellings</th>
</tr>
</thead>
<tbody>
<tr>
<td>spread</td>
<td>spred</td>
</tr>
<tr>
<td>sign</td>
<td>sine</td>
</tr>
<tr>
<td>scream</td>
<td>skreem or screem</td>
</tr>
<tr>
<td>dwarf</td>
<td>dwarf</td>
</tr>
<tr>
<td>bald</td>
<td>balled or borld</td>
</tr>
<tr>
<td>niche</td>
<td>nish or neesh</td>
</tr>
<tr>
<td>chrome</td>
<td>crome or croam or krome or kroam</td>
</tr>
<tr>
<td>plaid</td>
<td>plad</td>
</tr>
<tr>
<td>sieve</td>
<td>sive or siv</td>
</tr>
<tr>
<td>rhyme</td>
<td>rime</td>
</tr>
<tr>
<td>wand</td>
<td>wond</td>
</tr>
<tr>
<td>shove</td>
<td>shuv</td>
</tr>
<tr>
<td>crypt</td>
<td>kript</td>
</tr>
<tr>
<td>gnome</td>
<td>nome or noam</td>
</tr>
<tr>
<td>lymph</td>
<td>limf</td>
</tr>
<tr>
<td>ghoul</td>
<td>gool</td>
</tr>
<tr>
<td>goad</td>
<td>goed</td>
</tr>
<tr>
<td>cinch</td>
<td>sinch</td>
</tr>
</tbody>
</table>
References


Cardoso-Martins, C. (2001). The reading abilities of beginning readers of Brazilian Portu-
guese: implications for a theory of reading acquisition. Scientific Studies of Reading 5,
289–317.


Carrasco, M., and McElree, B. (2001). Covert attention accelerates the rate of visual infor-
mation processing. Proceedings of the National Academy of Science 98, 5363–5367.

in visual search: effects of display duration, target eccentricity, orientation and spatial

contrast sensitivity across the CSF: support for signal enhancement. Vision Research 40,
1203–1215.

fields: Effects of transient covert attention, spatial frequency, eccentricity, task and set

Carrasco, M., Williams, P. E., and Yeshurun, Y. (2002). Covert attention increases spatial
resolution with or without masks: Support for signal enhancement. Journal of Vision 2,
467–479.

targets having single and combined features. Perceptual and Motor Skills 82, 1155–1167.

efficiency are related in children. Cortex 34, 531–546.


149–180.


Dyslexia 39, 50–63.


References


References


References


References


References


References


